Name of class :-

semiconductor physics & Devices

EC 310

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28/2/2017

- Text :- Diffrent Books

- Grading system :-

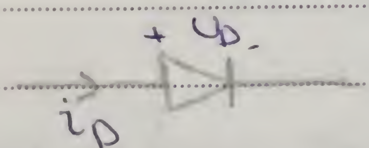
2 midterms 40% → 50%

one final 45% → 60%

Hws 5% → 10%

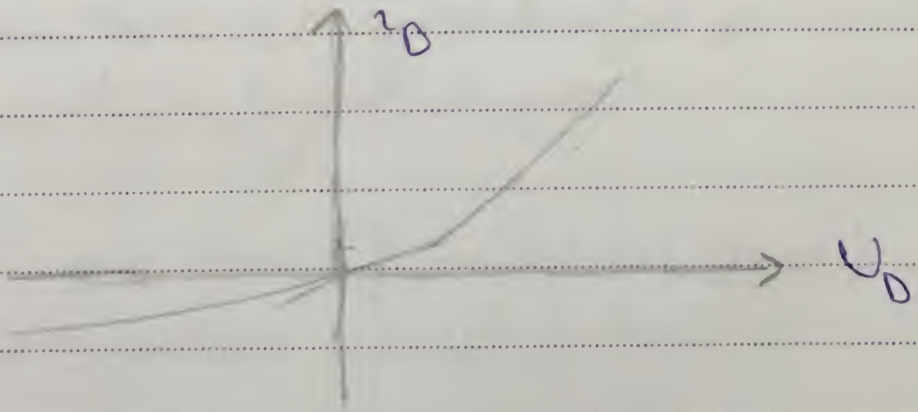
- Topics to be covered :-

1 - semiconductors materials.
2 - current flow in semiconductors.
3 - pn junction (Diode).



constant

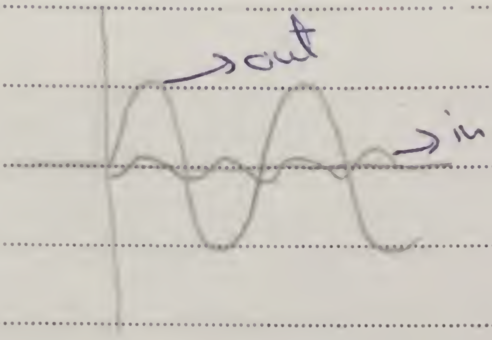
$$i_D = I_s\left(e^{v_D/V_T} - 1\right)$$



4- Diode circuits.

5- Bipolar junction transistor (BJT)

6- field effect transistor (FET).



Amply fire

$A_v = \frac{V_o}{V_{in}}$

* the names of the course:-

- Introduction to semi(conductors physics & Devices)
- solid state electronics

* electronic Devices used to ~~process~~ process information

(amplification of week signals + filtring + modulation + coding & Decoding)

تعديل/ تغيير

* Moore's law : device density on chip every two years.

- featured size (14 nm)

* Brief History :-

1^{st} half of 20th century (1900 → 1950)

Dominated by vaccum tubes.

- 1904 : fleming invented the valve الأنابيب المفرغة (vaccum tube diode)
- 1906 : Deforest oscallators multivibrator were designed using Diodes & Triodes ثلاثي الأقطاب
- 1920 : first radios station was created.
- 1930 : B & W TV introduction.
- 1940 : Radar was developed.
- 1946 : first electronic computer called electronic Integerator & numerical computer (ENIAC).

2^{nd} half of 20 century (1950 → ---)

- Dominated by solid state electronic devices.

* Semiconductors :-

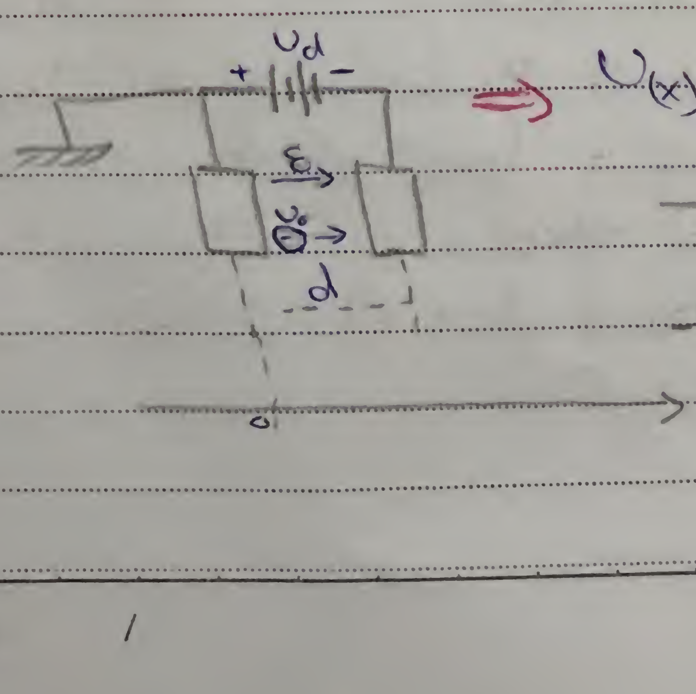
- controlled flow of charges is foundmental to the operation of electronic devices.

⟹ materials used must provide :-

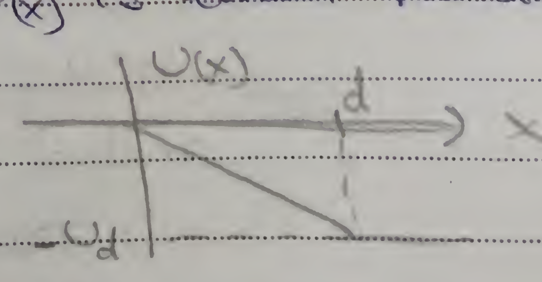
- mobile charges.
- process that governing the flow of mobile charges.

حاجز / عائق

* The potential energy barrier :-



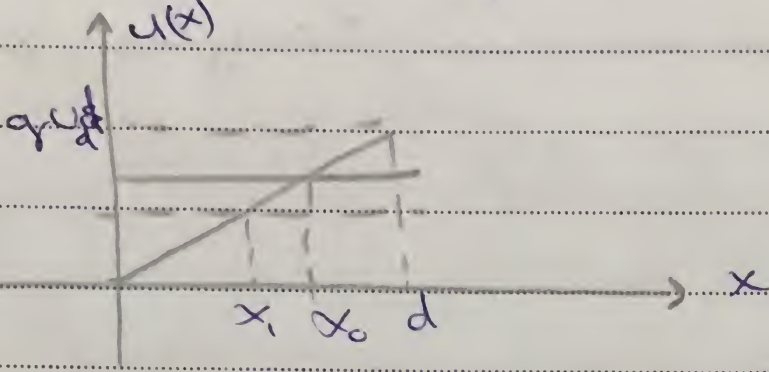
⟹ $V_{(x)}$ is linear function



تطابق / تناظر

- corresponding potential energy $u(x)$

$$u(x) = -q\,U(x)$$



* Total energy of electronics remains the same

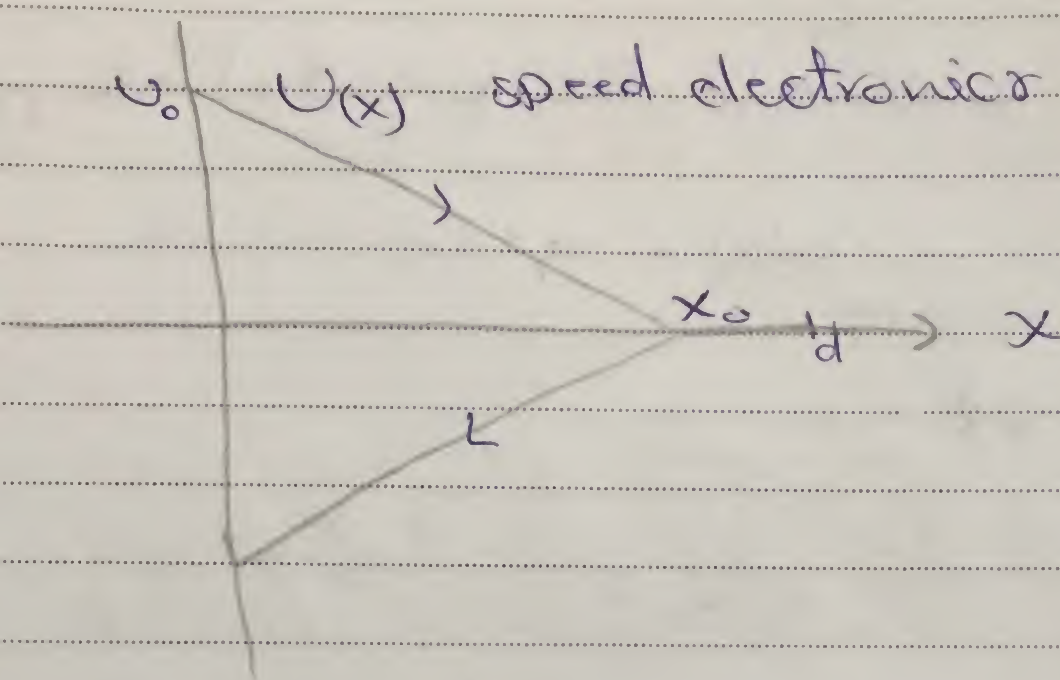
$w = u + k = -q\,U(x) + \frac{1}{2} m v^2 = \text{constant}$

max k at $A\ (x = 0) = \frac{1}{2} m v^2 = w$

min k at $x_0 = 0 \Rightarrow w = u$

$\Rightarrow$ x_0 = maximum distance the electron travel

$\Rightarrow$ The altration of direction of motion of electron at x_0 is a result of the potenical energy barier.



Subject:

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Energy Levels :-

منعزل

In an isolated atom each energy level

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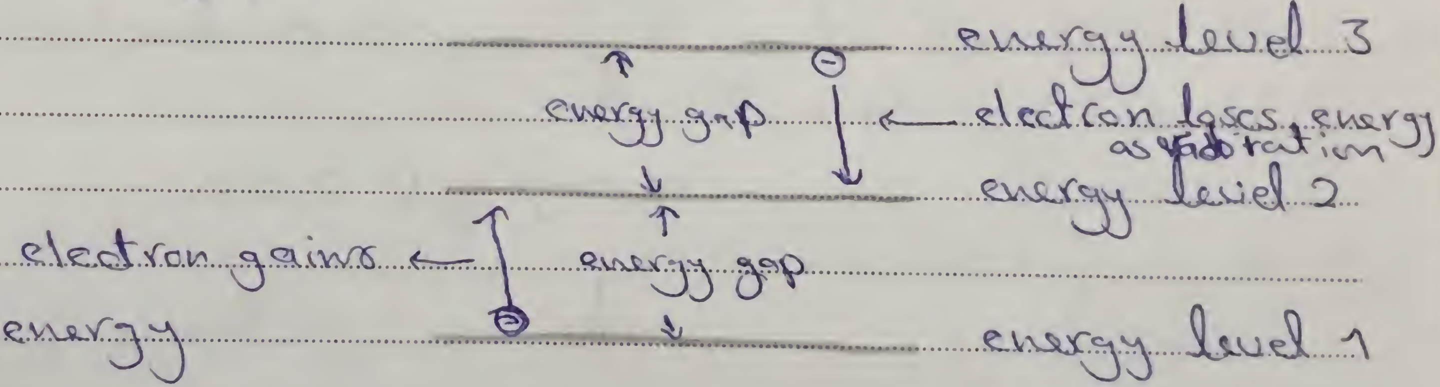
is associated orbiting electrons.

These energy levels are discute.

⟹ between energy levels are energy gaps in wich no electrons exist.



- The Transtion from hight to how energy level, the electron ~~gains~~ loses energy when as in transition from lower to high energy level, the electron gains energy.

* الالكترونات تمشي عكس اتجاه المجال

- when atoms are brought to form crystals, The discrete energy levels in the atoms are expanded (اتسع) in to energy band حزم

Two important bands are the ((valance band and conduction band)).

عوازل insulator :-

conduction band

↑

energy gap > 5 eV

↓

valence band

Sime conductors :-

conduction band

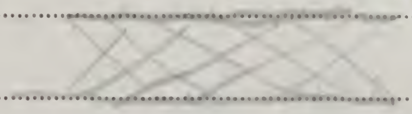
↑

energy gap ≅ 1.1 for si, 0.67 eV for Ge

↓

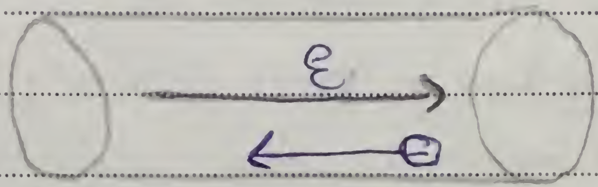
valence band

* conductors :-



$E_g = 0$

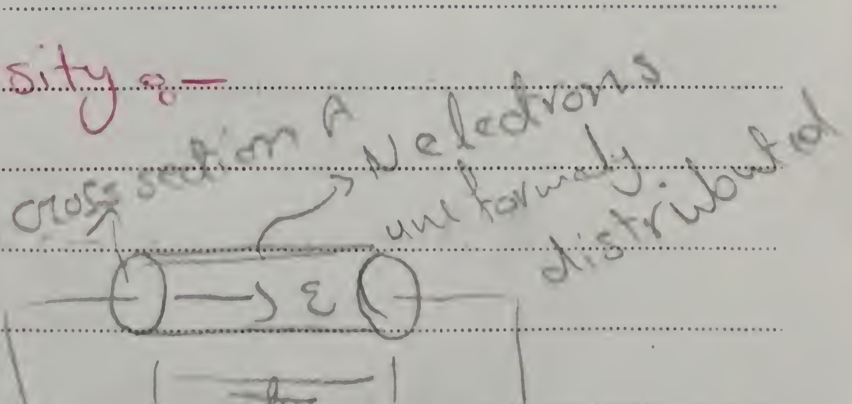
free electron in an electric field $\mathcal{E}$



The electrons drift (انسياق) in the direction opposite to $\mathcal{E}$ with a drift velocity v_d

$v_d = \mu_e \mathcal{E}$, μ_e = mobility of electron

* current density :-



$1 eV = 1.6 \times 10^{-19}$ Joule

under The inflame of the field, an electron travels a distance L in time T

$\Rightarrow \quad v_d = \frac{L}{T}$

I = current = Total charge crossing an area in unit time
= (charge per carier) x (# of cariers crossing the area in unit time)

$$= q \times \frac{N}{T} = \frac{qN}{T} \cdot \frac{L}{L} = \frac{qNv_d}{L}$$

J = current dinsity = $\frac{\text{current}}{\text{unit Area}}$

$$= \frac{I}{A} \quad \text{Amp}/m^2$$

$$= \frac{qNv_d}{LA}$$

التركيز

LA = volume $\Rightarrow \frac{N}{LA}$ = concentration

$$J = qnv_d \quad , \quad v_d = \mu \mathcal{E}$$

Subject: .... / /

$\bar{J} = q n \mu \mathcal{E}$ Amp/m^2

The conductivity $= \sigma = q n \mu$

$\bar{I} = \bar{J} A = \sigma \mathcal{E} A \cdot \frac{L}{L} = \frac{\sigma A}{L} (\mathcal{E} L)$

$$\boxed{= \frac{\sigma A}{L} V = \frac{V}{R}} \longrightarrow *$$

$R = \frac{1}{\sigma A} = \rho \frac{L}{A}$, ρ = resistivity (Ω-m)

$\rho = \frac{1}{\sigma}$

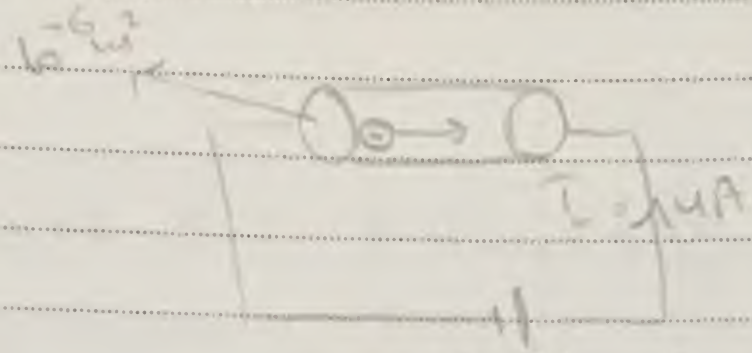
Example :-

a cupper conductor of 10^{-6} cross-section caries a 4 Amp current. determine the average electron drift velocity

Given $\rho = 1.73 \times 10^{-8}$ Ω-m

copper density = 8.9 g/cm^3

atom weight = 63.6



$V_d = \frac{IL}{qN} \cdot \frac{A}{A} = \frac{IV}{qAN}$

$= \frac{J}{qn}$

$V_d = \frac{IL}{qN} = \frac{J}{nq}$

$J = \frac{I}{A} = \frac{4 \text{ Amp}}{10^{-6} m^2} = 4 \times 10^6 \text{ Amp}/m^2$

find n :-

1 mole of copper = 63.6 grams

$\Rightarrow$ 63.6 grams of copper contains 6.022×10^{23} atoms

each copper atom contributes one free electron

$\Rightarrow$ n = # of free electrons in $1 m^3$

= # of atom in $1 m^3$

Volume of 1 mole = $\frac{63.6}{8.9} cm^3 = 7.14$

$1 m^3$ contains = $\frac{10^6 \times 8.9}{63.6}$ moles

$n = \frac{10^6 \times 8.9}{63.6} \times 6.022 \times 10^{23} = 8.43 \times 10^{28}$ electrons

Subject:

$$\therefore v_d = \frac{4\times10^{6}}{8.43\times10^{28}\times1.6\times10^{-19}} = \frac{4}{8.43\times1.6}$$

$$\simeq 3\times10^{-4}\ m/s$$

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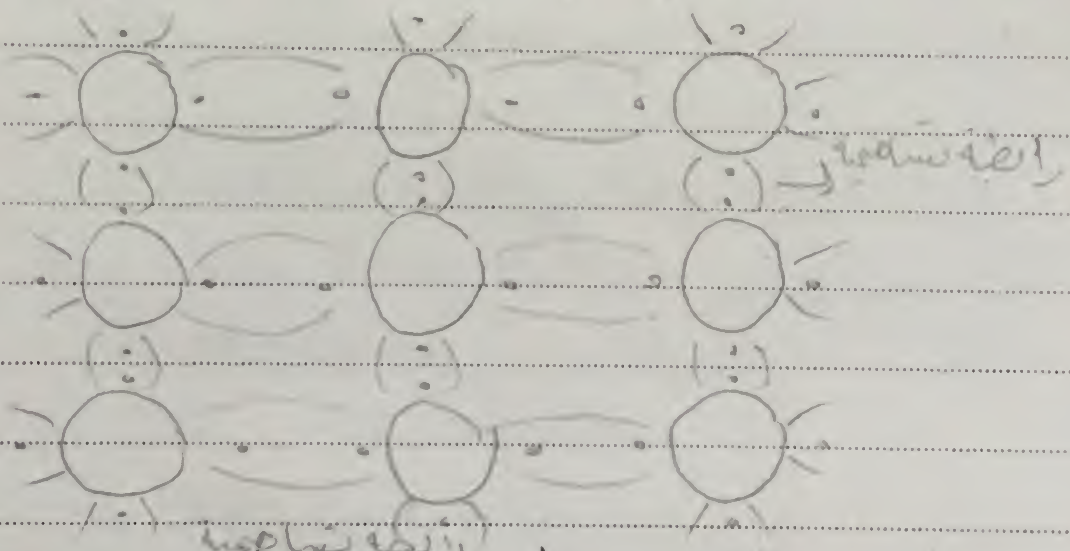
6/3/2017

محاضرة
اليوم فاتقايد

* Semi conductor materials :-

① elemented semi conducters :- الماتيريال الأساسية التي نتعامل معها

- silicon (Si) & Germanium (Ge)
- each atom contain 4 valance electrons
- Crystal structure of Si & Ge



- covalent Bonds are formed

② compound semi conductor

Breaking The covalent bond (freeing electrons) :-

* at $0K$ ($-273°C$):

covalent Bonds are very strong (Not possible to free electrons).

⇒ semi conducter is an insulator.

- it's nesessery to free electrons to make semiconductor suitable for conduction

⇒ This requires amount of energy is The energy gap E_g.

$E_g \cong 1.1\,eV$ for si & $E_g \simeq 0.67\,eV$ for Ge

* at room tempreture ($300K$):

a small of electrons possess this amount of energy & Break the covelant Bonds and become free.

- holes:- when an electrons Becoms free it leave behind a hole.

hole behaves a (+) charg.

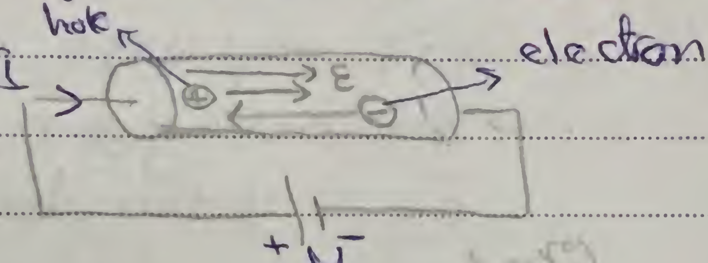
* الفجوات بتتحرك عكس الاتجاه بتاع الالكترون

- Generation (Breaking of a band) :-
  resulting in a free electron & a hole

  إعادة الإتحاد

- Recombination :-
  Reconstructing the covalent Band.

- in a present of electric field ($\mathcal{E}$)



$$J = (n\mu_n + p\mu_p)\, q\, \mathcal{E}$$

$q = e =$ electric charge (1.6×10^{-19} C)

$n =$ concentration of negatively charged carriers electrons

$p =$ concentration of positively charged carriers (holes)

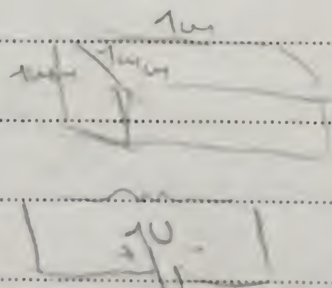
$\mu_n =$ Mobility of electrons.

$\mu_p =$ mobility of holes.

Properties of semi conductor

Property	units	si	Ge
Energy gap (E_g)	eV	1.1	0.67
μ_n	$\frac{cm^2}{V.sec}$	1350	3900
μ_p	"	480	1900
intrensic concentration (n_i)	$\frac{\# \text{ of carriers}}{cm^3}$	1.5×10^{10}	2.4×10^{13}
resistivity ρ	Ω-m	2300	0.46
density	g/m^3	2.33×10^{6}	5.32×10^{6}
atomic weight	g/mol	28.09	72.6

$$R = \rho \frac{L}{A} = 2300 \times \frac{1}{10^{-6}} = 2.3\times10^{9}\ \Omega$$



التيار يكون ضعيف جداً في المادة لان قابلية كثرة
الالكترونات والفجوات صغيرة جداً

- Intrensic si & Ge have very low conductivity because concentration of mobile carriers (electrons & holes is very low).
- In intrensic semi conductor each free electron creats a hole.

$\Rightarrow n = p = n_i$ → intrensic concentrations

توازن

At equilibrium, The number of electron hole pairs is constant.

زوج

Example :-

ratio of electron - holes pairs to the # of atom in si.

$$\frac{\#\ \text{of atoms}}{m^3} = \frac{2.33\times10^{6}}{\boxed{28.09}} \times 6.022\times10^{23}$$

atomic weight

$$\cong 5\times10^{28} = N$$

$$n_i = 1.5\times10^{16}/m^3$$

$$\frac{N}{n_i} = 3.3\times10^{12}$$

الرقم

يعني كل 3.3×10^{12} يوجد واحد الكترون حر

Intrensic conductivity σ_i :-

$$\sigma_i = (n\mu_n + p\mu_p)e = n_i(\mu_n+\mu_p)e$$

$$= 1.5\times10^{16} * (0.135 + 0.048) * 1.6\times10^{-19}$$

$$= 4.4\cancel{76}\times10^{-4}/\Omega\,m$$

$$\rho_i = \frac{1}{\sigma_i} \cong \cancel{8}\ 2.28\times10^{3}$$

/ /   Subject: ....

67 —> 68

11/3/2017

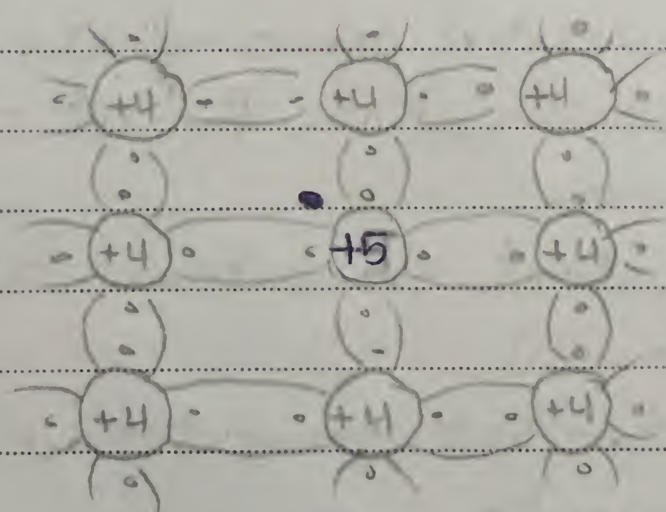
Extrensic semiconductors:-

- conductivity of semi conductor can be changed by adding impurities to an intrensic semiconductor (semi conductor becomes extrensic or doped semiconductor)
- The impurities in an elemental semiconductor are most often trivalent or pentavelant atoms. ثلاثي التكافؤ خماسي التكافؤ
- In elemental semiconductor.
  - base material are the 4^{th} column elemen
  - Trivalent element are 3^{rd} column element
  - pentavalent elements are 5^{th} column elements

+3	+4	+5
Boron(B)	Carbon(C)	Nitrogen(N)
Aluminum(Al)	silicon(Si)	Phosphorous(P)
Gallium(Ga)	Germanium(Ge)	Arsenic (As)
Indium(In)	Tin (Sn)	Antimony(Sb)

n-type semiconductors :-

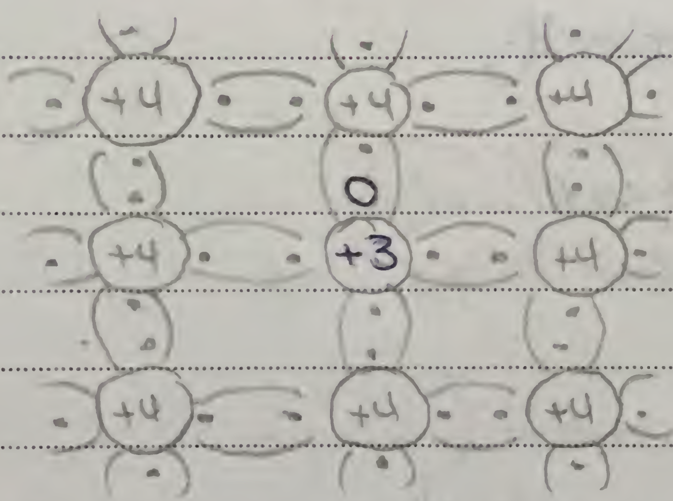
obtained by adding a 5^{th} column element as impurity (doping element).



- only about 0.05 eV is needed to free the 5^{th} electron of the Donor atom المانحة
- The 5^{th} column element are called donor impurities or n-type impurities

⇒ n increases ⇒ σ increases
resulting semiconductor is called n-type semiconductor

p-type semiconductors:-
obtained by adding a 3^{rd} column element as impurity (doping element)



القابلة

- The 3^{rd} column element are called Acceptor impurities or p-type impurities
⇒ p increases ⇒ σ increases
- resulting semiconductor is called p-type semiconductor.

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* In n-type semiconductor :
    - electrons are the majority carriers
    - holes are the minority carriers
* In p-type semiconductor :
    - holes are the majority carriers
    - electrons are the minority carriers

- The mass action law :-

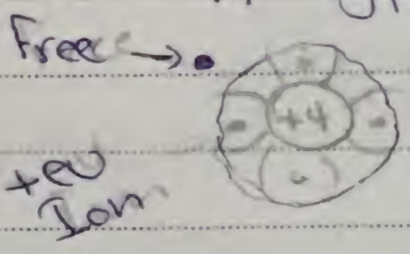
Theoretically

$$np = n_i^2$$

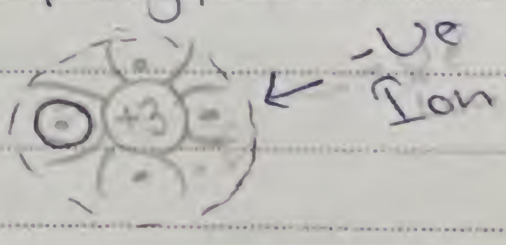
- Carrier concentration :-

small amount of energy is required to Ionize the impurity atoms.

n - type



p - type



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- Virtually all impurity atoms are Ionized at tempratures at wich electronic devices are normally operated ($>200°K$).

- let N_D = concentration of Donor atoms.
  N_A = concentration of acceptor atoms
- to maintain electric Neutrality.
- Total (+ve) charge = Total (-ve) charge

$$P + N_D = n + N_A$$

- In n-type semiconductor $N_A = 0$, $n \gg p$
  $\Rightarrow n \cong N_D$
  $\Rightarrow p \cong n_i^2 / N_D$
- In p-type semiconductor $N_D = 0$, $p \gg n$
  $\Rightarrow p \cong N_A$
  $\Rightarrow n \cong n_i^2 / N_A$

* Example:-
Determine the conductivity of a sample of a si doped with Arsenic in wich in every 10^6 atoms of si, an arsenic

atom is added   نوعه n-type لانه في صيغته
من المجموعة 5th

$\sigma = (n\mu_n + p\mu_p)q$

- semiconductor is n-type $\Rightarrow n = N_D$

مثال المحاضرة السابقة ← $N \cong 5\times10^{22} \dfrac{\text{atom of Si}}{cm^3}$

$\Rightarrow N_D = \dfrac{N}{10^6} = 5\times10^{16}$ atom of As/cm^3

$n = 5\times10^{16} \dfrac{\text{free electrons}}{cm^3}$

$p = n_i^2 / N_D = \dfrac{(1.5\times10^{10})^2}{5\times10^{16}} = \dfrac{2.25}{5}\times10^4$

$= 4.5\times10^3$ holes/cm^3

$\sigma = 1.6\times10^{-19}\left(\dfrac{5\times10^{16}}{cm^3} * \dfrac{1350\,cm^2}{V\text{-}s} + 4.5\times10^3 * 480\right)$

الضعف بسبب انها $= 10.8 \,/\Omega\text{-}cm$

لما كان Intrinsic

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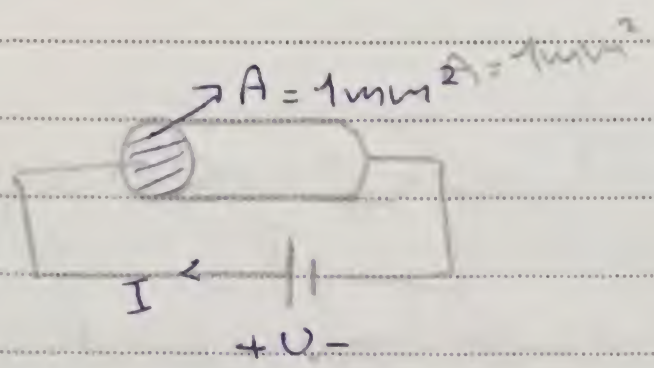
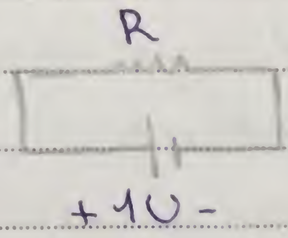




for intrensic Si

$$R = \rho \frac{L}{A} = \rho \frac{10\,cm}{10^{-2}\,cm^2} = \rho \frac{10^3}{cm} = 2280 \times 10^3\,\Omega$$

$$I = \frac{1}{R} = \frac{1}{2.28\times10^6}\,A = \frac{1}{2.28}\,\mu A$$

$$R = \rho \frac{l}{A} = \rho \frac{10\,cm}{10^{-2}\,cm} = 10^3 \rho = 10^3 \times 0.1 = 100\,\Omega$$

$$\Rightarrow I = \frac{1}{100} = 10\,mA$$

ff $= 38.4 / \Omega\text{-}cm$ = 10^5 مرة من الأولى الحالة

14/3/2017

امتحانات

Variation of semi conductors properties

$$\sigma = q\,(n\mu_n + p\mu_p)$$

for n-type , $n = N_D$, $p = n_i^2 / N_D$
for p-type , $p = N_A$, $n = n_i^2 / N_A$

μ_n μ_p & n_i are properties of the materials.

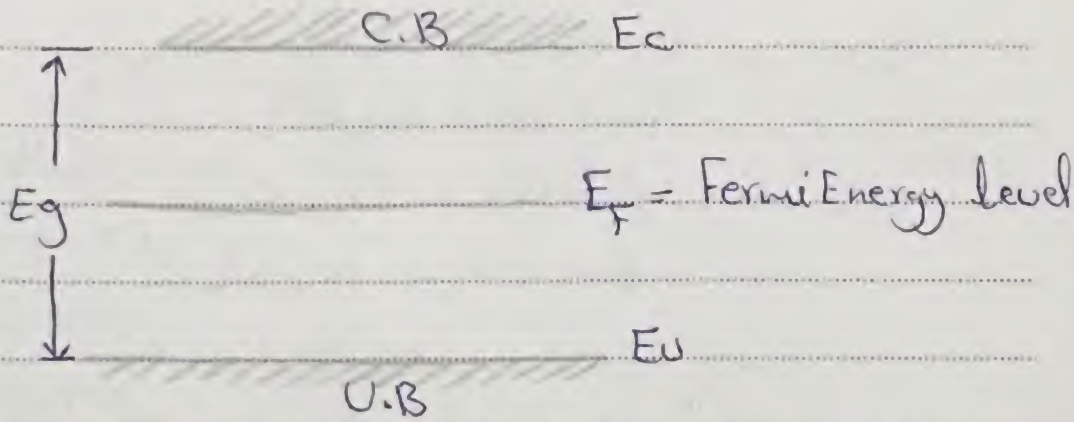
- n_i is function of tempreture.
- μ_n & μ_p are functions in tempreture & doping level, Electric field.

I) Variation of intrinsic concetration n_i with tempreture T :-

Some semiconductor physics results

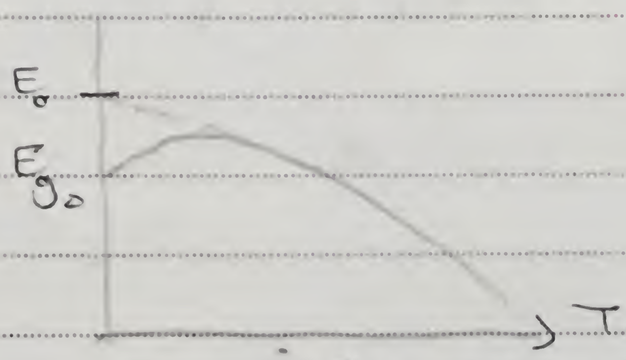
- K_B = Boltzman constant = 1.381×10^{-23} J/K
- h = plank's constant = 6.626×10^{-34} J-sec
- N_C = Density of states in the conduction Band

- N_v = Density of states in the valence band
- E_i = The intrensic Fermi Energy level E_F



- $E_g \triangleq$ Energy gap $(E_c - E_v)$

$$E_g \cong E_{g_0} - b_1 T$$



$$E_{g_0} = E_g \Big|_{T = 0K}$$

- $$N_c = 2\left(\frac{2\pi m_e^* k_B T}{h^2}\right)^{\frac{3}{2}}$$

- $$N_v = 2\left[\frac{2\pi m_h^* k_B T}{h^2}\right]^{\frac{3}{2}}$$

$m_e^* \triangleq$ effictive mass of electron

$m_h^* \triangleq$ effictive mass of hole

* for intrensic semiconductor :-

$$p = n = n_i$$

$$n = n_i = N_c e^{-(E_c - E_i)/k_B T}$$

$$p = n_i = N_v e^{-(E_i - E_v)/k_B T}$$

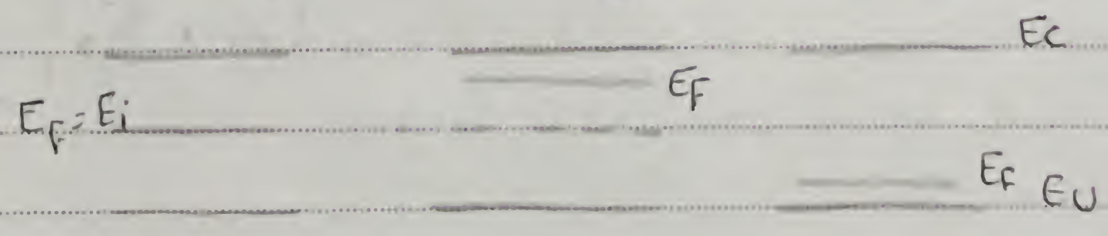
$$pn = n_i^2 = N_c N_v e^{(E_i - E_c + E_v - E_i)/k_B T}$$

$$= N_c N_v e^{-(E_c - E_v)/k_B T}$$

$$= N_c N_v e^{-E_g/k_B T}$$

$$\Rightarrow n_i = \sqrt{N_c N_v}\, e^{-E_g/2k_B T}$$

intrensic n-type p-type



$$N_v N_c = \left(2\left[\frac{2\pi m_h^* k_B T}{h^2}\right]\right)^{3/2}\left(2\left[\frac{2\pi m_e^* k_B T}{h^2}\right]\right)^{3/2}$$

$$= 4\left(\frac{2\pi k_B T}{h^2}\right)^3 (m_h^* m_e^*)^{3/2}$$

$$\sqrt{N_c N_v} = 2\left(\frac{2\pi k_B T}{h^2}\right)^{3/2} (m_h^* m_e^*)^{3/4}$$

$$\sqrt{N_c N_v} = k_2 T^{3/2} \quad , \quad k_2 = 2\left(\frac{2\pi k}{h^2}\right)^{3/2} (m_h^* m_e^*)^{3/4}$$

$$n_i = k_2 T^{3/2} e^{-E_g/(2k_B T)}$$

* for Si ⇒ $n_i(T) \cong 1.76 \times 10^{16} T^{3/2} e^{-\frac{4550}{T}}$ /cm^3
* for Ge ⇒ $n_i(T) \cong 3.88 \times 10^{16} T^{3/2} e^{-7000/c}$ /cm^3

* II) Carrier mobility variation:-

Carrier mobility is affected by by carrier تشتت scattering mainly [lattic & ionized impurity scattering].

- For T: 100 → 400 K $\mu \propto T^{-m}$ m=2.5 for e

⇒ μ decreases with increasing tempreture T because

as T increases ⇒ more carriers ⇒ more اصطدام collisions ⇒ lower mobility

- depen of μ on electric field $\mathcal{E}$
  - μ_n is constant for $\mathcal{E} < 10^3$ V/cm
  - $\mu_n \propto \sqrt{\mathcal{E}}$ for $10^3 \leq \mathcal{E} < 10^4$ V/cm

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- mobility also function of doping level.

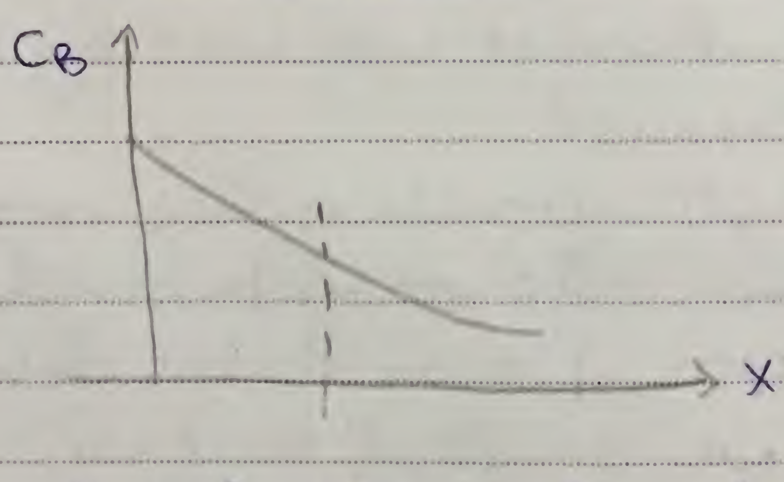
* conductivity variation
  n_i increases with T
  μ decreases with T

$|\Delta n_i| > |\Delta \mu| \Rightarrow \sigma_i$ increases with T

$\sigma_i = n_i(\mu_n + \mu_p)q$

* Current flow by diffusion :-

انتشار Diffusion of particles occurs (يحدث) in the direction of (عكس) -ve Gradient of particle concentration



Particle diffuse from left to right crossing the surface @ x_0

Particle flux across a surface at x_0 defined as the net number of particles crossing the surface per unit area per unit time

i.e. particle flux $= F_0 = -D \dfrac{dC_B}{dx}$

$\dfrac{dC_B}{dx}$ = concentration gradient

$D \triangleq$ Diffusivity / Diffusion coefficient / Diffusion constant

In-3D $\quad C_B = C_B(x,y,z) \Rightarrow F_0 = F_0(x,y,z)$

$F_0 = -D \underbrace{\nabla C_B}$ → Gradient of C_B

$$\nabla C_B = \left[\frac{\partial B}{\partial x}, \frac{\partial B}{\partial y}, \frac{\partial B}{\partial z} \right]$$

⇒ Diffusion current density $= J_D = q(-D\nabla C_B)$

if particles are electrons ⇒ $J_{nD} = qD\nabla C_B$

if particles are holes ⇒ $J_{pD} = -qD\nabla C_B$

*Enstein's relation :-

relation between μ & D

current density has a drift component & diffusion component.

for electrons in n-type

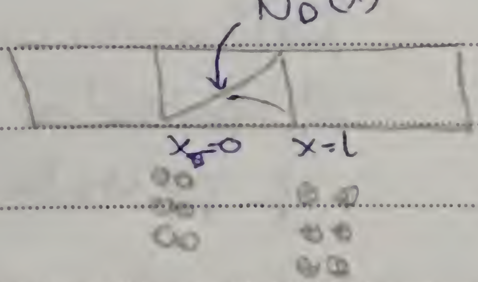
$$J_n = q\underbrace{\mu_n n \mathcal{E}}_{\text{Drift component}} + \underbrace{q D_n \nabla n}_{\text{Diffusion component}}$$

consider a ~~nx~~ -unit formly doped n-type semi conductor

$$n = N_D \Rightarrow n(x) \;\&\; N_D(x)$$

$$\nabla n = \frac{dn}{dx}$$

electrons diffuse to the left of $x = l$ leaving behind ionized donors and causing some electrons to accumulate at $x = 0$



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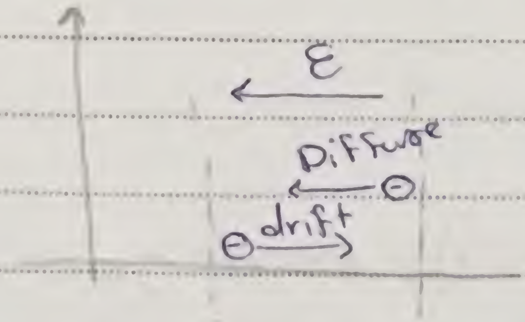

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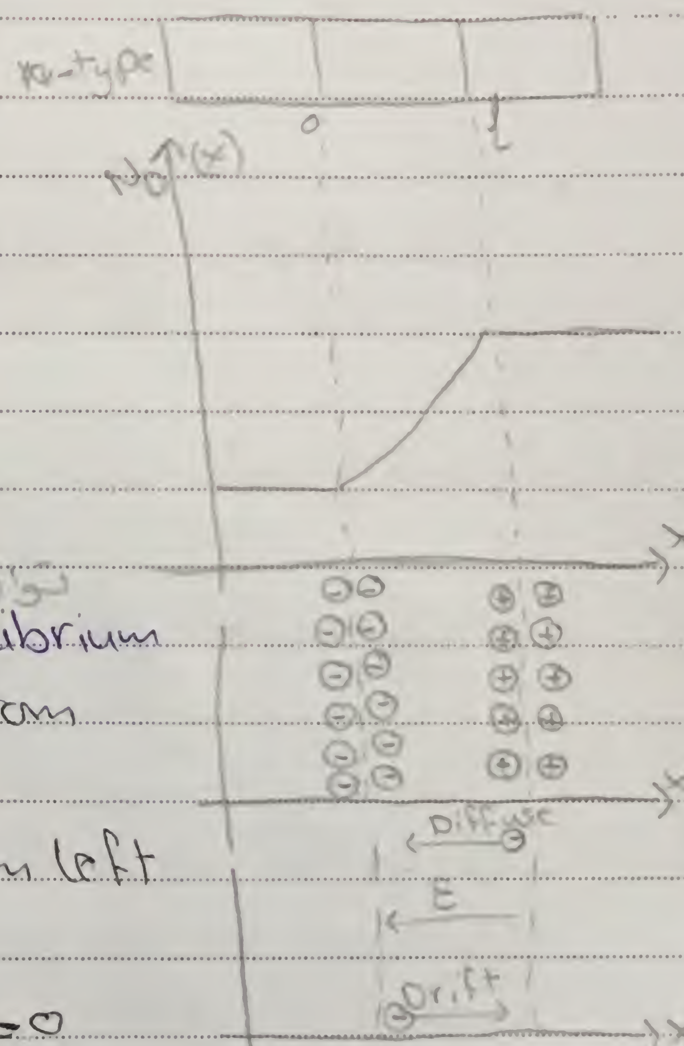
current flow by diffusion :-



For $0 \leq x \leq l$, vause with x $N_D(0) = N_1$

$N_D(l) = N_2$

$n(x) = N_D(x)$

$$\nabla n = \frac{dn(x)}{d(x)}$$

In thermenal equilibrium

- electron diffuse from right to left
- electron drift from left to right

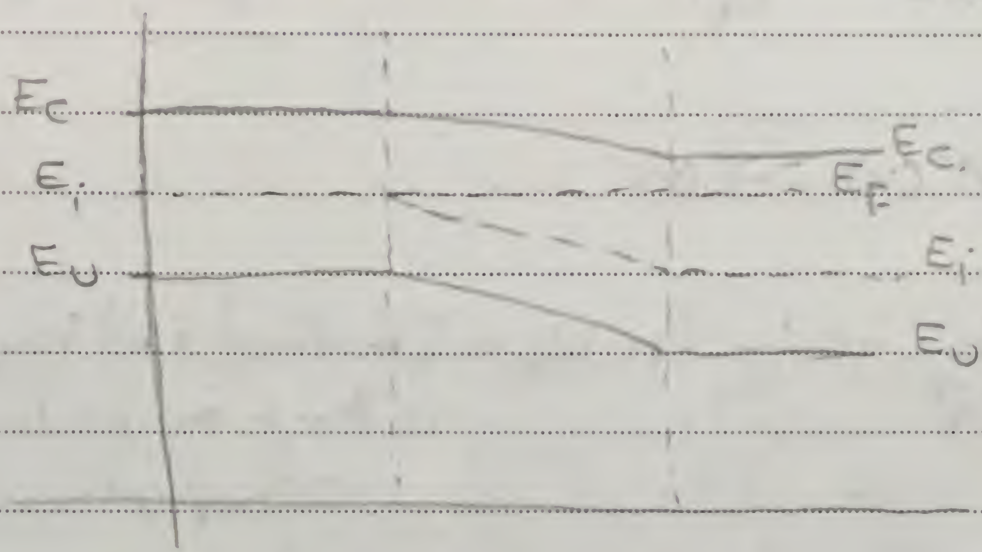
But net current = 0

$\Rightarrow J_n = 0$

$$J_n = q\mu_n n \mathcal{E} + q D \frac{dn}{dx} = 0 \text{ @ any } (x)$$

Energy band Diagram :-

Let $N_A = n_i$



E_F = Fermi Energy level

E_i = Intrensic fermi energy level

E_c = Botton of conduction Band

E_v = Top of Valence Band Energy level

$$n = n_i e^{(E_F - E_i(x))/K_B T}$$

$$E_i(x) = -q\,\phi(x)$$

$$E_F - E_i(x) = E_i(0) - E_i(x) = -q[\phi(0) - \phi(x)]$$

let $\phi(0) = 0 \Rightarrow E_F - E_i(x) = q\,\phi(x)$

/ /

Subject:

$$n = n_i\, e^{q\phi(x)/K_BT}$$

$$\Rightarrow \frac{dn}{dx} = \frac{q n_i}{K_BT}\, e^{q\phi(x)/K_BT}\, \overbrace{\frac{d\phi(x)}{dx}}^{\phi'(x)} = \frac{q}{K_BT}\, n\,\phi'(x)$$

وبيطلع

$$\phi'(x) = -\mathcal{E}(x)$$

$$\frac{q}{K_BT} = \frac{1}{V_T}\,, \quad V_T =$$ Thermal voltage or voltage equivalent of Temprature

@ room temprature $V_T = 0.02568\,V$
$= 25.68\,mV$

Back to in thermenal equilibrium :-

$$q D_n \frac{dn}{dx} = q D_n \frac{q}{K_BT}\, n\,\phi'(x) = -q \frac{D_n n \mathcal{E}}{V_T}$$

$$J_n = q\mu_n n\mathcal{E} - q\frac{D_n}{V_T} n\mathcal{E} = qn\mathcal{E}(\mu_n - D_n/V_T) = 0$$

$$\mu_n - \frac{D_n}{V_T} = 0 \Rightarrow \left\| \frac{D_n}{\mu_n} = V_T \right\|$$ Eienstiens relation

also $D_p / \mu_p = V_T$

The Built-in potential $\phi(x)$:-

$$J_n = q D_n \frac{dn}{dx} + q \mu_n n \mathcal{E} = 0$$

$$\mathcal{E} = - \frac{D_n}{n \mu_n} \frac{dn}{dx} = \frac{-V_T}{n} \frac{dn}{dx}$$

But $\mathcal{E} = -\frac{d\phi(x)}{d(x)} \Rightarrow \frac{-d\phi(x)}{dx} = -\frac{V_T}{n} \frac{dn}{dx}$

$$\Rightarrow d\phi(x) = V_T \frac{dn}{dx}$$

$$\phi(x) = \int_0^x d\phi(x) = V_T \int_{n(0)}^{n(x)} \frac{dn}{n} = V_T \ln n(x) \Big|_{n(0)}^{n(x)}$$

$$= V_T \left[\ln n(x) - \ln n(0) \right] = V_T \ln \left(\frac{n(x)}{n(0)} \right)$$

$$V = V_T \ln \left(\frac{n(\ell)}{n(0)} \right)$$

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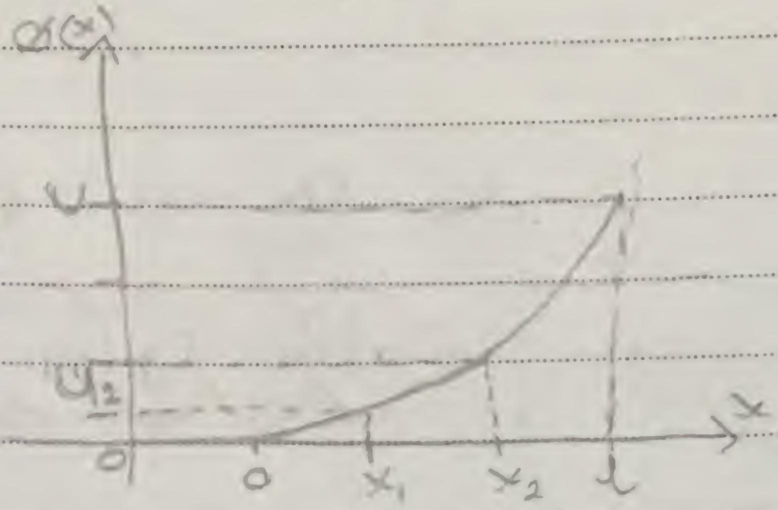
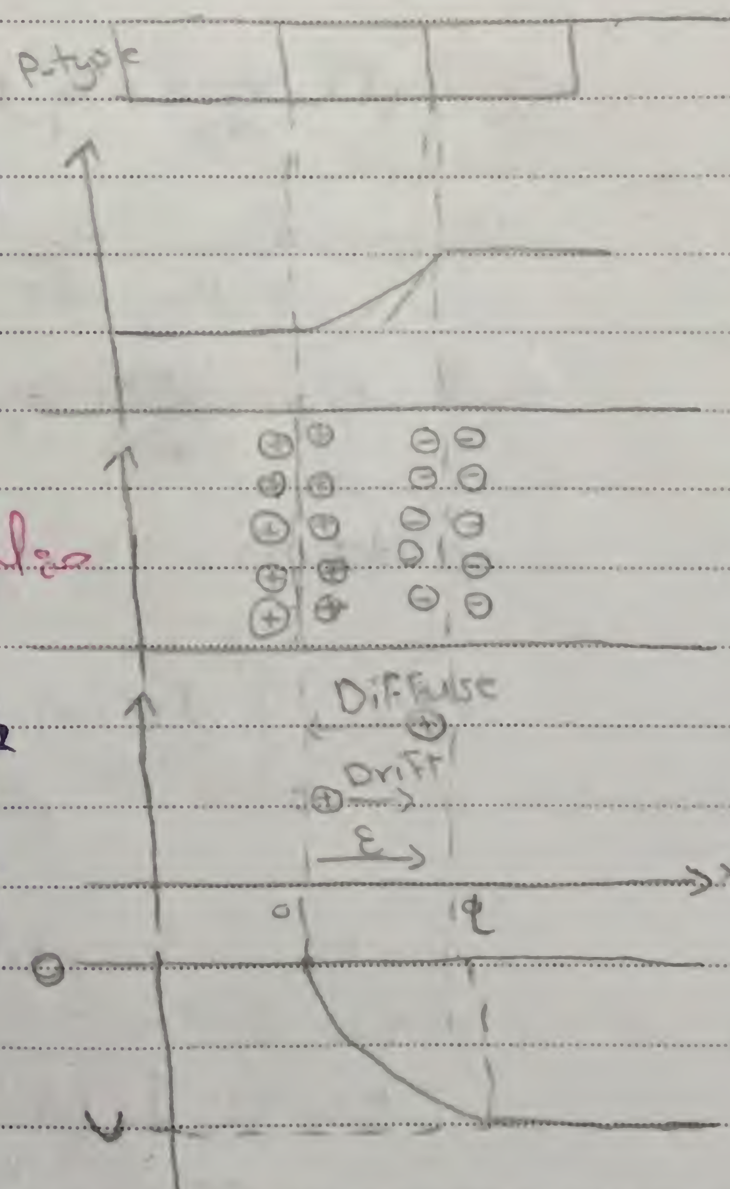
Subject: ....

$$U_{12} = U_T \ln \frac{n(x)_2}{n(x_1)}$$



$$\phi(x) = -U_T \ln\left(\frac{P(x)}{P(0)}\right)$$

$$U = -U_T \ln\left(\frac{P(l)}{P(0)}\right)$$



For n-type materials:

Let $n(x) = n_i$ @ $x = x_2$

$$\Rightarrow U_n = \phi(x_2) - \phi(x_1)$$

$$= U_T \ln\left(\frac{n(x_2)}{n(x_1)}\right)$$

$$= U_T \ln\left(\frac{n_2}{n_1}\right)$$

$$\frac{V_n}{V_T} = \ln \frac{n_2}{n_1} \Rightarrow \frac{n_2}{n_1} = e^{V_n/V_T} \Rightarrow n_2 = n_1 e^{V_n/V_T}$$

$$n_1 = n_2 e^{-V_n/V_T}$$

For p-type :-

$$P(x_1) = P_1 \,,\quad P(x_2) = P_2$$

$$V_p = \varnothing(x_2) - \varnothing(x_1) = -V_T \ln \frac{P(x_2)}{P(x_1)}$$

$$= -V_T \ln \frac{P_2}{P_1} \Rightarrow \frac{P_2}{P_1} = \frac{-V_p}{V_T}$$

$$\Rightarrow P_2 = P_1 e^{-V_p/V_T} \Rightarrow P_1 = P_2 e^{V_p/V_T}$$

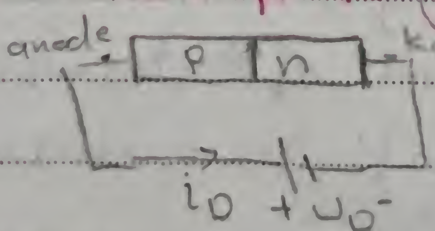
$$n_2 P_2 = n_1 e^{V_n/V_T} \; P_1 e^{-V_p/V_T} = n_1 P_1 e^{(V_n - V_p)/V_T}$$

For the same type semi conductor

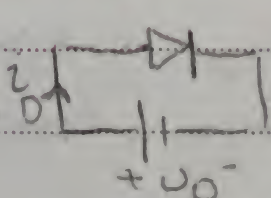
$$V_n = V_p$$

$$\Rightarrow n_2 P_2 = n_1 P_1 \Rightarrow np = n_i^2 \quad \text{(mass action law)}$$

* The p-n junction :-



$\Rightarrow$



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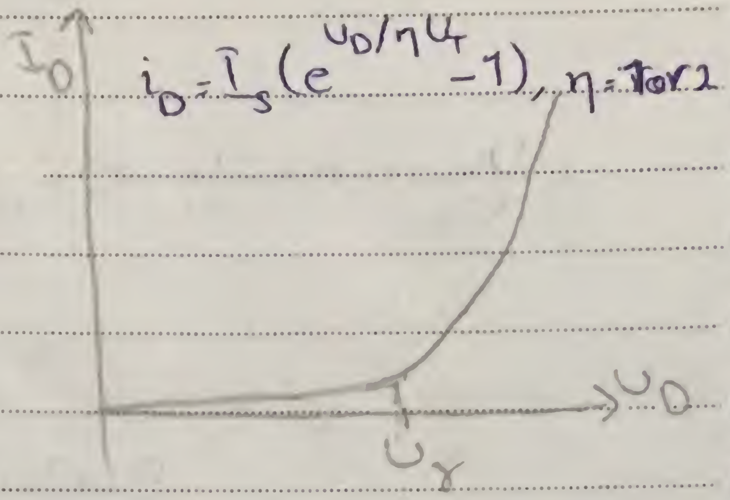
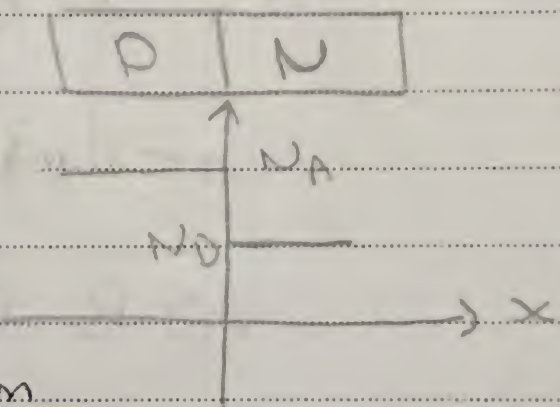
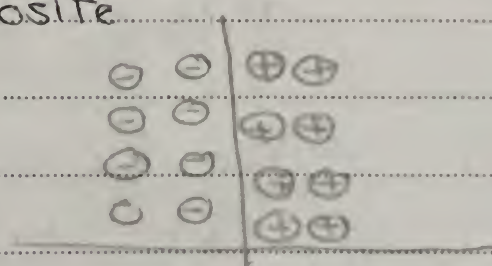
$i_D = I_s(e^{v_D/\eta V_T} - 1), \quad \eta = 1 \text{ or } 2$





The step (abrupt) junction

- Carrier concentration
- holes diffuse from p to n around the junction
- electron diffuse in opposite direction.



Notation :-

n_{no} = concentration of electrons in neutral n-region.

p_{no} = Concentration of holes in neutral n-region

n_{po} = Concentration of electrons in neutral p-region

p_{po} = concentration of holes in neutral p-region

P_p = concentration of holes in p-region
n_p = concentration of electron in p-region
n_n = concentration of electron in n-region
P_n = concentration of holes in n-region
$P_p = P_{po}$ in neutral p-region $= N_A$
$n_n = n_{no}$ in neutral n-rgion $= N_D$

$$\Rightarrow n_{po} = \frac{n_i^2}{P_{po}} = n_i^2 / N_A$$

$$P_{no} = n_i^2 / N_D$$

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- holes diffuse from left to right leaving behind (-ve) ions.
- electrons diffuse from right to left leaving behind (+ve) ions.

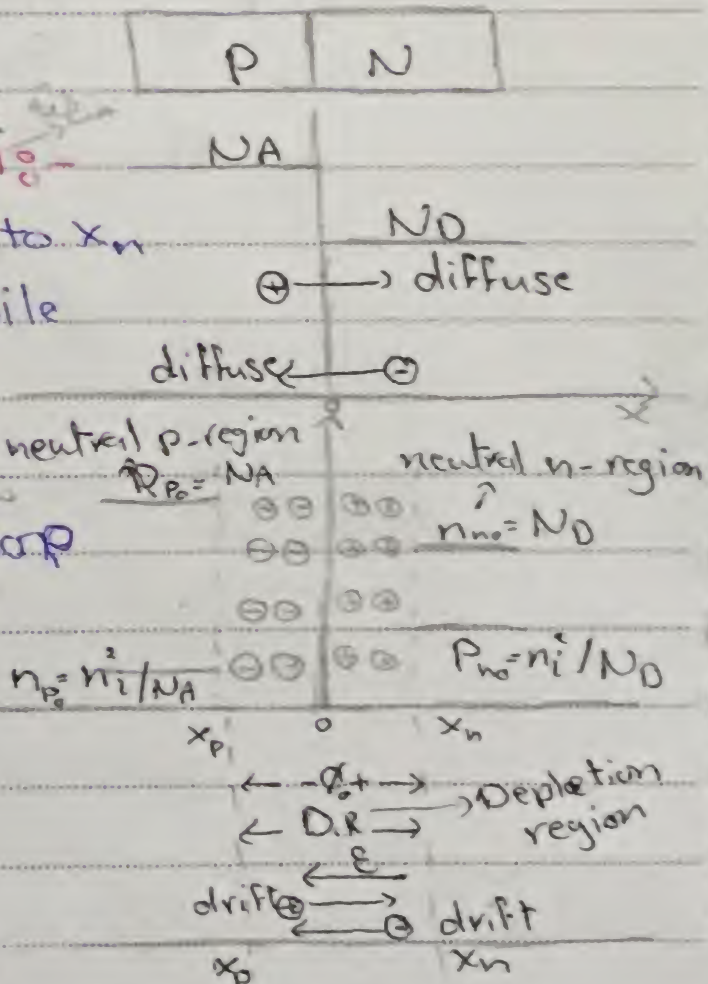
The depletion Region:-

« Region from from x_p to x_n Depleted from mobile charges »

- The ions on the sides of the junction develop a potential difference

⇒ Electric field develops across the junction.

⇒ This field is quite larg, it sweeps away the mobile carrier from the depletion region.



Subject: ....

d = drift   D = Diffusion

خارجي   تحيز

At no external bias

No current flows

$I = 0$

حاصل/محصلة

$\Rightarrow$ net current density

$= \bar{J} = 0$

خارج التوازن   امكانية

The equilibrium barrier potential (ϕ_0)

if is built in potential about the junction ϕ_0 is developed such ~~as~~ that the drift current is just equals ~~to~~ to the diffusion current to meet $\bar{J} = 0$

$$\bar{J} = \bar{J}_n + \bar{J}_p \ , \ \bar{J}_n = \bar{J}_{nd} + \bar{J}_{nD} \ , \ \bar{J}_p = \bar{J}_{pd} + \bar{J}_{pD}$$

هنا طالما كان مسلم الموجب والسالب يتحركون في نفس الاتجاه

$$\bar{J} = 0 \Rightarrow \text{Either } \cancel{\bar{J}_n = -\bar{J}_p} \text{ or } \bar{J}_n = \bar{J}_p = 0$$

يعتبر

- Consider $\bar{J}_p = 0$: $(x_p \le x \le x_n)$

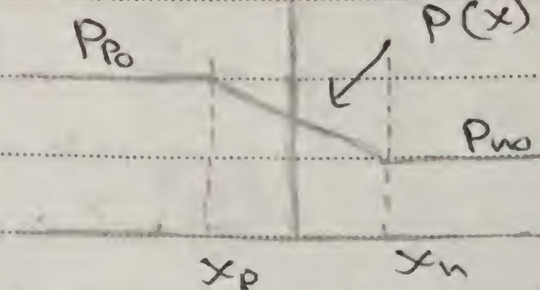
$$\Rightarrow \bar{J}_{pd} + \bar{J}_{pD} = q \mu_p P(x) \mathcal{E}(x) - q D_p \frac{dP(x)}{dx} = 0$$

$$\boxed{\mathcal{E}(x) = V_T \frac{dP(x)}{dx \Delta x} \Rightarrow P(x) \mathcal{E}(x) - \frac{D_p}{\mu_p} \frac{dP(x)}{dx} = 0}$$

??

Subject: ....   /   /

$$P(x)\,\mathcal{E}(x) = V_T \frac{dP(x)}{dx}$$



$$\mathcal{E}(x) = -\frac{d\phi(x)}{dx}$$

$$\Rightarrow d\phi(x) = -\mathcal{E}(x)\,dx = -V_T \frac{dP(x)}{P(x)}$$

$$\phi(x) = \int_{-\infty}^{x} d\phi(\lambda) = \int_{-\infty}^{x_p} d\phi(\lambda) + \int_{x_p}^{x} d\phi(\lambda)$$

$$= \phi_p + \int_{x_p}^{x} d\phi(\lambda)$$

$$= \phi_p - V_T \int_{x_p}^{x} \frac{dP(x)}{P(\lambda)} = \phi_p - V_T \ln P(\lambda)\Big|_{x_p}^{x}$$

$$\phi(x) = \phi_p - V_T \ln \frac{P(x)}{P(x_p)} = \phi_p + V_T \ln \frac{P(x_p)}{P(x)}$$

$$= \phi_p + V_T \ln \frac{P_{P_0}}{P(x)}$$

@ $x = x_n$

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at $x = x_n$

$$\phi(x) = \phi_n = \phi_p + V_T \ln \frac{P_{po}}{P_{no}}$$

$$\phi_n = \phi_p + V_T \ln \frac{N_A}{n_i^2/N_D} = \phi_p + V_T \ln \frac{N_A N_D}{n_i^2}$$

$$\boxed{\phi_0 = \phi_n - \phi_p = V_T \ln \frac{N_A N_D}{n_i^2}}$$

$$\phi_0 = V_T \ln \frac{P_{po} n_{no}}{n_i^2} \Rightarrow \frac{P_{po} n_{no}}{n_i^2} = e^{\phi_0/V_T}$$

$$\phi_0 = V_T \ln \frac{P_{po}}{P_{no}} \Rightarrow \frac{P_{po}}{P_{no}} = e^{\phi_0/V_T}$$

$$\Rightarrow P_{po} = P_{no} e^{\phi_0/V_T} , \quad P_{no} = P_{po} e^{-\phi/V_T}$$

Similary :-

$$J_n = 0 \Rightarrow n_{no} = n_{po} e^{\phi_0/V_T}$$

$$n_{po} = n_{no} e^{-\phi_0/V_T}$$

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Depletion → Doping Region

- The potential ϕ_o present a barrier against further diffusion of mobility carriers.

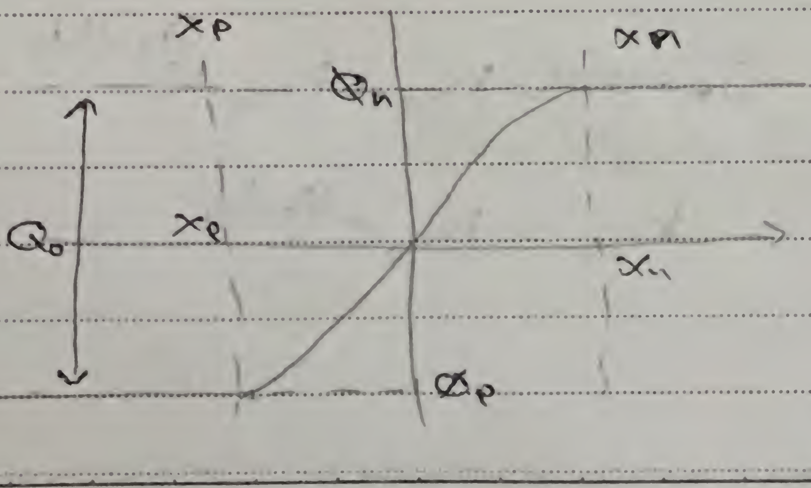
Example:

Determine ϕ_p, ϕ_n, ϕ_o for a step si P-n junction at 300K with $N_A = 10^{18}/cm^3$, $N_D = 10^{15}/cm^3$, Assume $n_i = 1.5\times10^{10}/cm^3$, $V_T = 26mV$

$$\phi_p = -V_T \ln \frac{N_A}{N_i} \cong -468mV$$

$$\phi_n = V_T \ln \frac{N_D}{n_i} \cong 289mV$$

$$\phi_o = \phi_n - \phi_p \cong 0.757V$$



الرسمة تبع المسألة

$$\Phi_0 = \Phi_n - \Phi_p = V_T \ln N_A N_D$$

$$= V_T \ln \frac{N_A}{n_i} \frac{N_D}{n_i}$$

$$= \underbrace{V_T \ln \frac{N_A}{n_i}}_{\text{منطقة الصنوب}} + V_T \ln \frac{N_D}{n_i}$$

* The depletion region charge :-

$\Phi_0 \cong 1\,0V$, $x_d < 1\,\mu m$

$\Rightarrow \mathcal{E} \cong 10^4\ V/cm$ in the depletion region

توزيع الايونات الغير متنقلة

* distribution of immobile ions :-

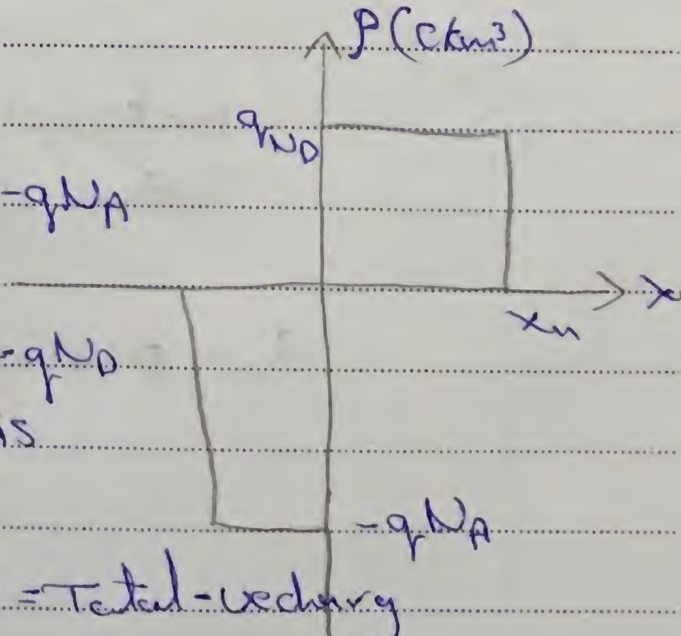
« No mobile charges »

for $x_p < x \leq 0$

charge density $= \rho = -qN_A$

for $0 < x \leq x_n \Rightarrow \rho = qN_D$

also assume a dipole is



$\Rightarrow$ Total charge +ve = Total -ve charg

$\Rightarrow q N_D (A x_n) = -q N_A (A x_p)$, $x_n > 0$, $x_p < 0$

$N_D x_n = N_A |x_p| \Rightarrow N_D |x_n| = N_A |x_p|$

The electric field $\mathcal{E}(x)$:-

$\mathcal{E}_o = 0$ for $x \leq x_p$ & $x \geq x_n$

from Gauss' law: $\frac{d\mathcal{E}(x)}{dx} = \rho / \epsilon$

ρ = charge density

ϵ = Dielectric permitivity of the material $= \epsilon_r \epsilon_o$

ϵ_r = relative dielectric permiticity of the material

material	Si	Ge	GaAs
ϵ_r	11.68	16.2	12.9

ϵ_o = permiticity of free space $= 8.85 \times 10^{-14}$ F/cm

/ /

Subject: ....

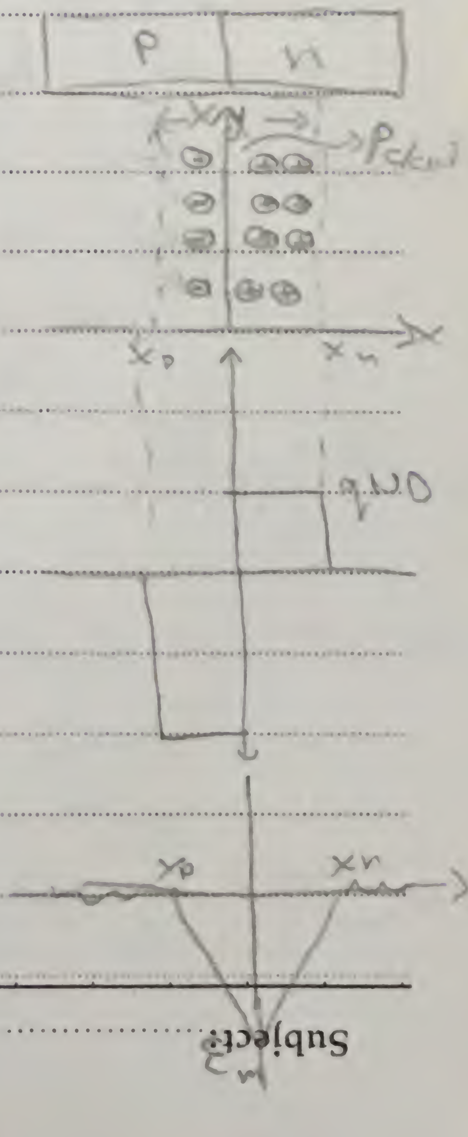
28/3/2017

The electric field :-

$\mathcal{E} = 0 \quad \text{for} \quad x \leq x_p \ \& \ x \geq x_n$

$\dfrac{d\mathcal{E}(x)}{dx} = \rho/\epsilon \Rightarrow d\mathcal{E}(x) = \dfrac{\rho}{\epsilon}\, dx$

$\rho = 0 \quad \text{for} \quad x \leq x_p \ \& \ x \geq x_n \Rightarrow \mathcal{E}(x) = 0$



for $x_p \leq x \leq 0$:

$\rho(x) = -qN_A$

$\mathcal{E}(x) = \displaystyle\int_{x_p}^{x} \frac{\rho}{\epsilon}\, dx$

$= \dfrac{-qN_A}{\epsilon} \displaystyle\int_{x_p}^{x} = \dfrac{-qN_A}{\epsilon}(x - x_p)$

@ $x = 0 \quad \mathcal{E}(x) = \dfrac{qN_A\, x_p}{\epsilon}$

for $0 < x \leq x_n$

$\mathcal{E}(x) = \mathcal{E}(0) + \displaystyle\int_{0}^{x} \frac{qN_D}{\epsilon}\, dx$

$$\Rightarrow \mathcal{E}_0 + \frac{qN_D}{\epsilon}\int_0^x dx = \mathcal{E}(0) + \frac{qN_D}{\epsilon}x$$

$$\mathcal{E}(x) = \frac{qN_A x_p}{\epsilon} + \frac{qN_D}{\epsilon}x$$

@ $x = x_n$, $\mathcal{E} = 0$

$$0 = \frac{qN_A x_p}{\epsilon} + \frac{qN_D x_n}{\epsilon}$$

$$\mathcal{E}_m = \mathcal{E}(0) = \frac{qN_A x_p}{\epsilon} = -\frac{qN_D x_n}{\epsilon}$$

for $x_p \leq x \leq 0$

$$\mathcal{E}(x) = -\frac{qN_A}{\epsilon}(x - x_p)$$

$$= \frac{qN_A}{\epsilon}(x - x_p)$$

$$= \frac{qN_A x_p}{\epsilon} - \frac{qN_A x}{\epsilon}$$

$$= \mathcal{E}_m - \frac{qN_A x}{\epsilon}$$

$$\boxed{= \mathcal{E}_m - \frac{qN_A x_p}{\epsilon x_p}x}$$

$\mathcal{E}_m = (1 - x/x_p)$

for $0 \le x \le x_n$

$$\mathcal{E}(x) = \mathcal{E}_m + \frac{qN_D x}{\epsilon} = \mathcal{E}_m + \frac{qN_D x_n x}{x_n}$$

$$\mathcal{E}(x) = \mathcal{E}_m(1 - x/x_n)$$

$$\therefore \mathcal{E}(x) = \begin{cases} 0 & \text{for } x \le x_p \ \& \ x \ge x_n \\ \mathcal{E}_m(1 - x/x_p) & \text{for } x_p \le x \le 0 \\ \mathcal{E}_m(1 - x/x_n) & \text{for } 0 \le x \le x_n \end{cases}$$

$$\mathcal{E}_m = \frac{qN_A x_p}{\epsilon} = -\frac{qN_D x_n}{\epsilon}$$

Since $\mathcal{E}(x) = -d\phi(x)/dx \Rightarrow \phi(x) = -\int \mathcal{E}(x)dx$

@ $x = x_p$, $\phi(x) = \phi_p$ & @ $x = x_n$, $\phi(x) = \phi(n)$

for $x_p \le x \le 0$

$$\phi(x) = \phi_p - \int_{x_p}^{x} \mathcal{E}(x)\,dx = \phi_p - \int_{x_p}^{x} \mathcal{E}_m\left(1 - \frac{x}{x_p}\right)dx$$

Subject: / /

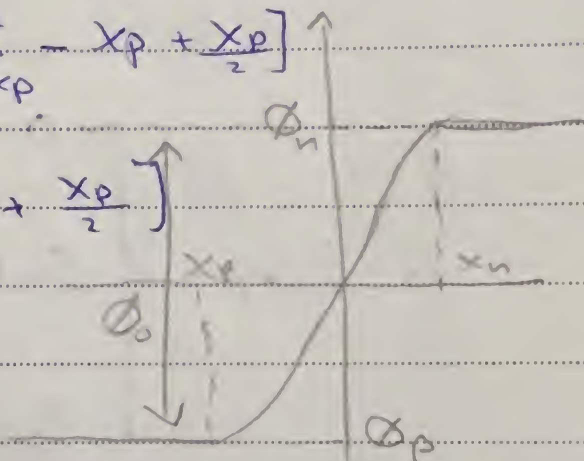
$$\phi(x) = \phi_p - \mathcal{E}_m \int_{x_p}^{x} (1 - x/x_p)\, dx$$

$$= \phi_p - \mathcal{E}_m \left[x - \frac{x^2}{2x_p} \right]_{x_p}^{x}$$

$$= \phi_p - \mathcal{E}_m \left[\left(x - \frac{x^2}{2x_p}\right) - \left(x_p - \frac{x_p^2}{2x_p}\right) \right]$$

$$\phi(x) = \phi_p - \mathcal{E}_m \left[x - \frac{x^2}{2x_p} - x_p + \frac{x_p}{2} \right]$$

$$\phi(x) = \phi_p + \mathcal{E}_m \left[\frac{x^2}{2x_p} - x + \frac{x_p}{2} \right]$$



for $0 \le x \le x_n$

$$\phi(x) = \phi(0) - \int_0^x \mathcal{E}(x)\, dx$$

@ $x = 0$, $\phi(0) = \phi_p + \mathcal{E}_m \dfrac{x_p}{2} = 0$

$$\phi_p = \frac{-\mathcal{E}_m x_p}{2}$$

By the same arg x you can show that

$$\phi_n = \frac{\mathcal{E}_m x_n}{2}$$

can also show that

$$\phi(x) = \frac{qN_A x_p}{2\epsilon}\left(x x_p - x^2/2\right) \quad \text{for } x_p \leq x \leq 0$$

$$\Rightarrow \phi_p = \frac{-qN_A x_p^2}{2\epsilon}$$

$$\phi_n = \frac{-\mathcal{E}_m x_n}{2} = \frac{qN_D x_n^2}{2\epsilon}$$

$$\phi(x) = \frac{qN_D}{\epsilon}\left(x x_n - x^2/2\right) \quad \text{for } 0 \leq x \leq x_n$$

$$\phi_0 = \phi_n - \phi_p = \frac{qN_D x_n^2}{2\epsilon} + \frac{qN_A x_p^2}{2\epsilon}$$

$$= \frac{q}{2\epsilon}\left[N_D x_n^2 + N_A x_p^2\right]$$

The width depletion region :-

$$\mathcal{E}_m = \frac{qN_A x_p}{\epsilon} = \frac{-qN_D x_n}{\epsilon}$$

هنفرض ال n تاب ولما بيكون doping level أقل
من n

$$\Rightarrow N_A|x_p| = N_D|x_n|$$

$$|x_p| = \frac{N_D}{N_A}|x_n| \quad , \quad |x_n| = \frac{N_A}{N_D}|x_p|$$

$$\Rightarrow \phi_0 = \phi_n - \phi_p = \frac{q}{2\epsilon}\left[N_D x_n^2 + N_A \frac{N_D^2}{N_A} x_n^2\right]$$

$$\phi_0 = \frac{q N_D x_n^2}{2\epsilon}\left[1 + \frac{N_D}{N_A}\right] = \frac{q x_n^2 N_D}{2\epsilon N_A}\left[N_A + N_D\right]$$

$$|x_n| = \sqrt{\frac{2\epsilon N_A \phi_0}{q N_D (N_A+N_D)}} \quad \text{also} \quad |x_p| = \sqrt{\frac{2\epsilon \phi_0 N_D}{N_A q (N_A+N_D)}}$$

$$x_d = |x_n| + |x_p|$$

$$= \sqrt{\frac{2\epsilon\phi_0}{q(N_A+N_D)}}\sqrt{\frac{N_A}{N_D}} + \sqrt{\frac{2\epsilon\phi_0}{q(N_A+N_D)}}\sqrt{\frac{N_D}{N_A}}$$

$$= \sqrt{\frac{2\epsilon\phi_0}{q(N_A+N_D)}}\left\{\sqrt{\frac{N_A}{N_D}} + \sqrt{\frac{N_D}{N_A}}\right\}$$

$$= \sqrt{\frac{2\epsilon\phi_0 (N_A+N_D)}{q N_A N_D}}$$

can show that

$$\mathcal{E}_m = \frac{-qN_D}{\epsilon}\sqrt{\frac{2\epsilon\phi_0 N_A}{qN_D(N_A+N_D)}} = \sqrt{\frac{2qN_AN_D\phi_0}{\epsilon(N_A+N_D)}}$$

$$|x_n| = x_d\left(\frac{N_A}{N_A+N_D}\right), \quad |x_p| = x_d\left(\frac{N_D}{N_A+N_D}\right)$$

The Depletion Region charge :-

$$Q = \int \rho\, dv = \rho v$$

cross section area

$$Q_j = -qN_A A|x_p| \leftarrow \text{-ve charg}$$

$$= qN_D A|x_n| \leftarrow \text{+ve charg}$$

$$= AqN_D\sqrt{\frac{2\epsilon N_A\phi_0}{qN_D(N_A+N_D)}} = A\sqrt{\frac{2\epsilon qN_DN_A\phi_0}{N_A+N_D}}$$

The Junction capacitance (Depletion layer capa-citance)

$$C_j = \frac{d\varnothing_j}{d\varnothing} \quad @ \text{ No external bias}$$

$$C_j = C_{jo}\ , \quad \varnothing = \varnothing_o$$

$$C_{jo} = \left.\frac{d\varnothing_j}{d\varnothing}\right|_{\varnothing=\varnothing_o} = A\sqrt{\frac{2\varepsilon q N_A N_D}{N_A + N_D}}\ \frac{1}{\sqrt{\varnothing_o}}$$

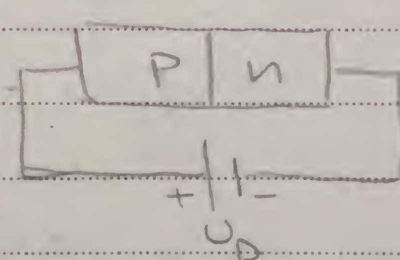
الانحياز الخارجي

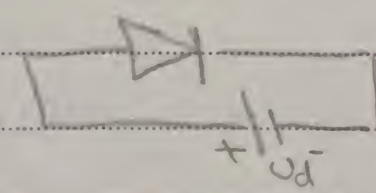
P-n junction with external bias:-

افتراض

يظهر

Assumption:- The external bias appears directly across the junction Depletion region

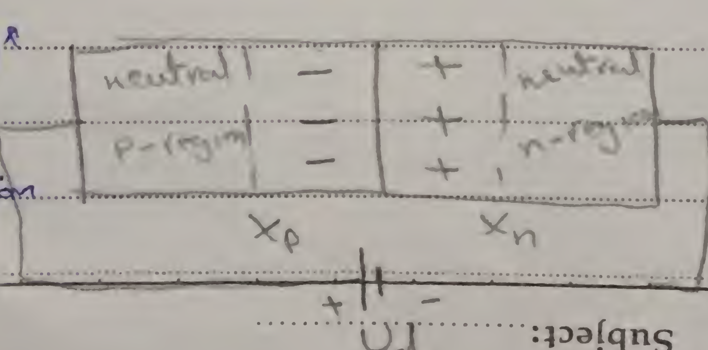




$R_p \leq R_d$, $R_n \leq R_d$

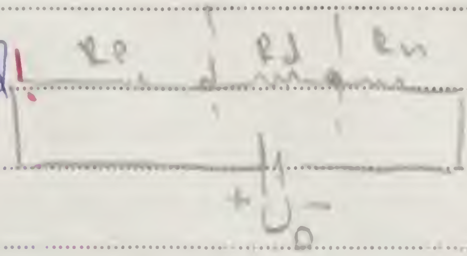
⇒ most of the voltage appears across R_d

i.e across the depl-Region

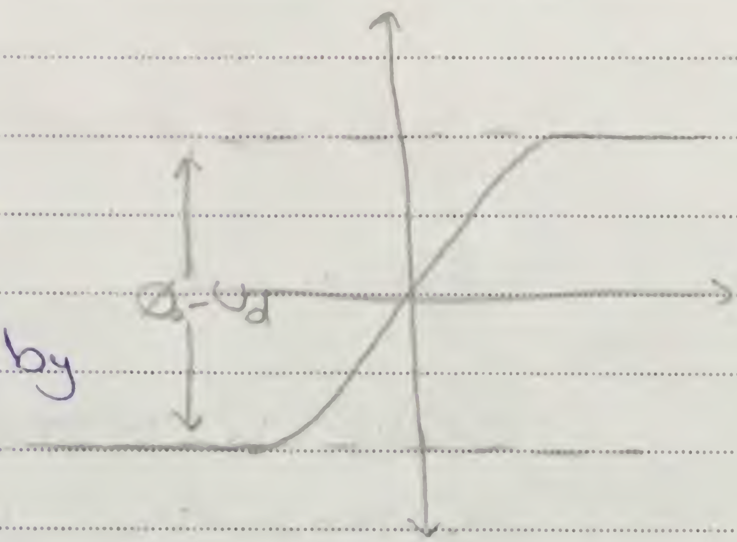


شرح برسمة (يوضحها)

what is the barrier potential!



$$\phi = \phi_0 - V_D$$



in all formula
ϕ_0 is replaced by
$\phi_0 - V_d$ when the
Junction is biased by
an external
voltage V_d

28/3/2017

Tutorial

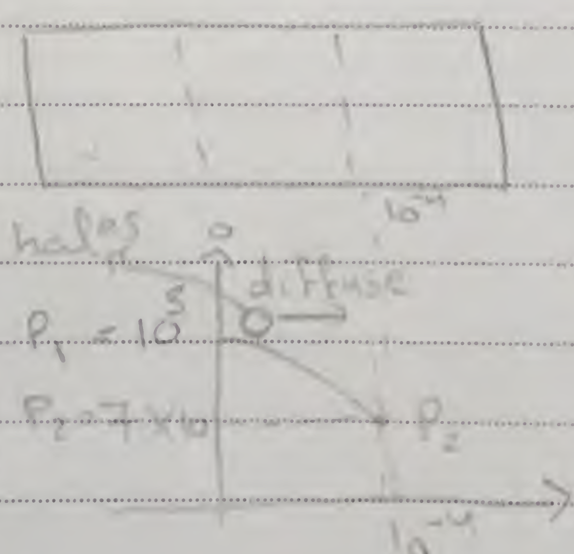
solution of home worke one :-

Problem 18 :-

$P(x) = 10^{3}(1 - 3\times10^{3})/cm^{3}$, $0 \leq x \leq 10^{-4} cm$

$\mu_n = 400\ cm^2/V.s$, $\mu_p = 300\ cm^2/V.s$

(A) $J_{PDiff} = J_{PDiffuse}$ A



$J_{PDiff} = -q\, D_p \nabla P$

$\frac{D}{\mu} = V_T \Rightarrow D_p = V_T \mu$

$\frac{dP(x)}{dx} = -3\times10^{6}\ \frac{holes/cm^3}{cm}$

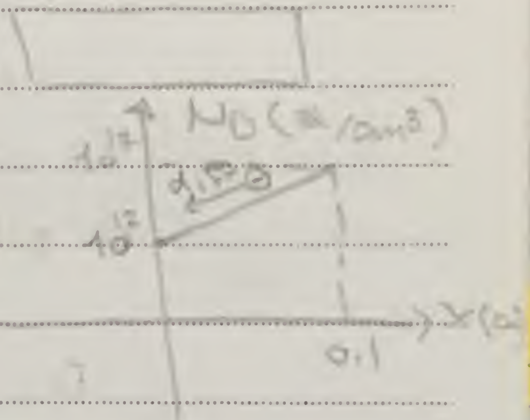
(B) $V_1 = -V_T \ln\left(\frac{P_2}{P_1}\right) = -25 \ln\left(\frac{7\times10^{2}}{10^{3}}\right)$

$$\mathcal{E}(x) = \frac{v_1}{10^{-4}\,cm} = 10^4\, v_1 / cm$$

Problem "74":-

$$D_n = 22.5\ cm^2/s$$

$$D_p = 5.2\ cm^2/s$$



$$n(x) = 10^{12} + \frac{10^{17} - 10^{12}}{0.1} x$$

$$n(x) \cong 10^{12} + 10^{18} x$$

$$J_{Dn} = qD_n \nabla = qD_n \frac{dn}{dx} = qD_n \times 10^{18}$$

$$p(x) = \frac{n_i^2}{n(x)}$$

$$J_{DP} = -qD_p \nabla p$$

Subject: .... / /

Problem "64":-

find T such that $n_i(T) = N_A = 10^{17}/cm^3$

for si :-

$E_g = 1.12 eV$, $N_c = 2.78 \times 10^{18}/cm^3$

$N_v = 9.84 \times 10^{18}/cm^3$

تركيز الالكترونات في C.B

$$n = N_c e^{-(E_c - E_F)/K_B T}$$

$$P = N_c e^{-(E_F - E_v)/K_B T}$$

$$np = N_c N_v e^{-(E_c - E_v)/K_B T}$$

$$n_i^2 = N_c N_v e^{-E_g/K_B T}$$

$$n_i = \sqrt{N_c N_v} \, e^{-E_g/2K_B T} = N_A$$

$T =$

Problem "3" :-

n-type silicon

$\rho = 5\,\Omega.cm$ @ $300k^{\circ}$

$\mu_n(300) = 1500\ cm^2/V.s$

$\mu_n(T) = C_1 T^{-3/2}$

$\rho = \frac{1}{\sigma} \Rightarrow \sigma = 0.2\ /\Omega.cm$

$\sigma_n = q n \mu_n\ ,\ n = N_D = \frac{\sigma_n}{q\mu_n}$

@ $T = 200k^{\circ} \Rightarrow \mu_n = C_1 T^{-\frac{3}{2}}$

$\Rightarrow C_1 = \frac{\mu_n(300)}{300^{-\frac{3}{2}}} =$

$\mu_n(200^{\circ}k) =$

@ $T = 400k^{\circ}$

$\mu_n(400) =$

/ / Subject: ....

Problem "1" :

$$f(E) = \frac{1}{1 + e^{(E-E_F)/k_BT}}$$

$\boxed{a}$

$$\Rightarrow 10^6 = 1 + e^{(E-E_F)/k_BT}$$

$$\frac{E-E_F}{k_BT} = \cancel{10^6}\ 13.815$$

$$T = \frac{0.55 \times 10^{-19} \times 1.66}{13.815 \times 1.38 \times 10^{-23}}$$

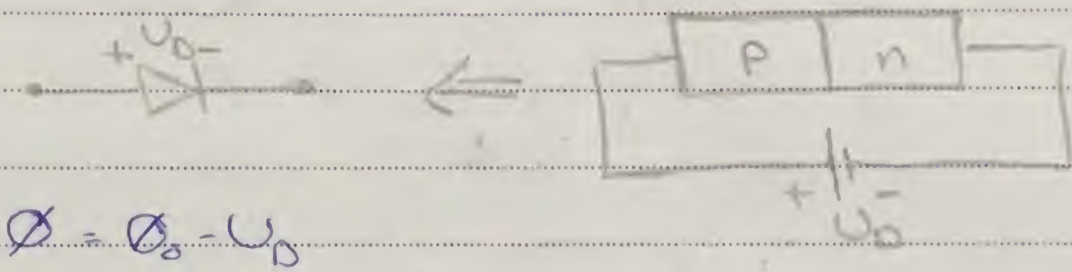
$$T =$$

$\boxed{B}$

1/4/2017

Biased p-n Junction:-

modify equition by replacing ϕ_0 by $\phi - V_d$



$$\phi = \phi_0 - V_D$$

$$N_I = \frac{N_A N_D}{N_A + N_D}$$

$$\mathcal{E}_m = \sqrt{\frac{2q N_A N_D}{\epsilon (N_A + N_D)}} \sqrt{\phi_0 - V_D}$$

$$Q_j = \sqrt{2\epsilon q N_I} \sqrt{\phi_0 - V_D}$$

$$= - \sqrt{\frac{-2q N_I}{\epsilon}} \sqrt{\phi_0 - V_D}$$

Junction capacitance:

$$C_j = \frac{dQ}{d\phi} , \quad \phi = \phi_0 - V_D , \quad d\phi = -dV_D$$

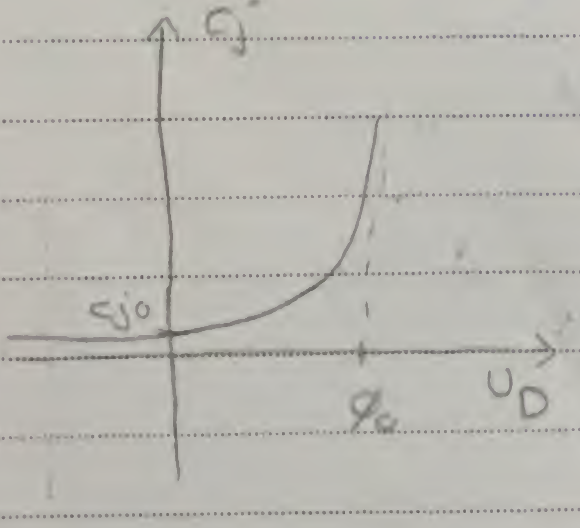
Parameters

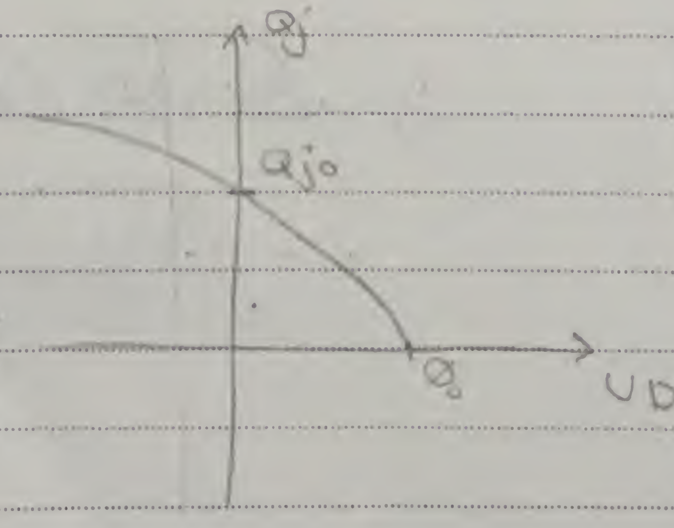
$$C_j = -\frac{dQ_j}{dV_D} = \sqrt{2\epsilon q N_I}\left(\frac{1}{2}\frac{1}{\sqrt{\phi_0 - V_D}}\right)$$ per unit area

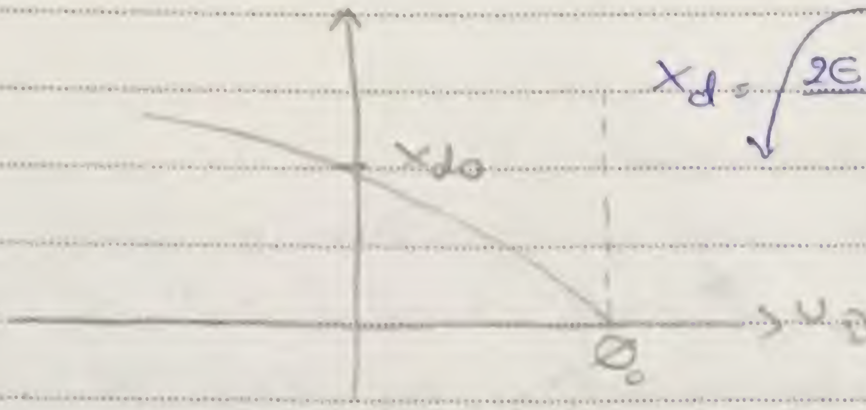
$$C_j = A\sqrt{\frac{\epsilon q N_I}{2}}\frac{1}{\sqrt{\phi_0 - V_D}}$$

$$= \left(A\sqrt{\frac{\epsilon q N_I}{2}}\frac{1}{\sqrt{\phi_0}}\right)\frac{1}{\sqrt{1 - V_D/\phi_0}}$$

$$= \frac{C_{j0}}{\sqrt{1 - \frac{V_D}{\phi_0}}}$$ → junction capacitance @ no bias

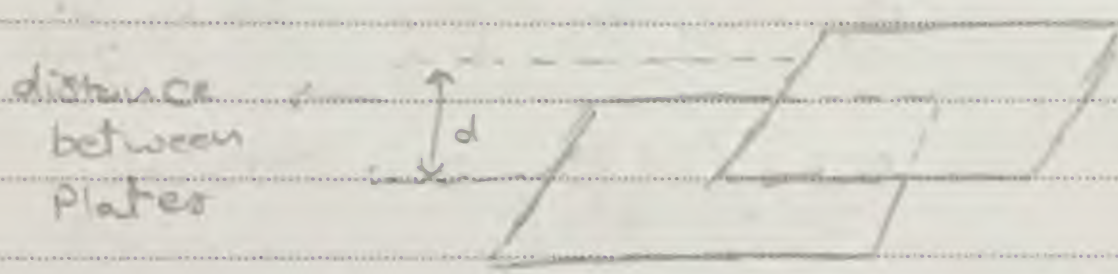






$$x_d = \sqrt{\frac{2\epsilon(\phi_0 - V_D)}{qN_I}}$$

considering the junction capacitance as a parellel plate capacitor



$$C = \frac{\epsilon A}{d}$$

Permiticity of dielectric between plates

cross section area

$$C_j = \frac{\epsilon A}{x_d} = \frac{\epsilon A}{\sqrt{\frac{2\epsilon(\phi_0 - V_D)}{qN_I}}}$$

$V_d = +0.5V$

$dV = -1V$

Example :-

Si step pn junction @ 300k° with $N_A = 10^{15}/cm^3$, $N_D = 10^{15}/cm^3$, $n_i = 1.5\times10^{10}/cm^3$

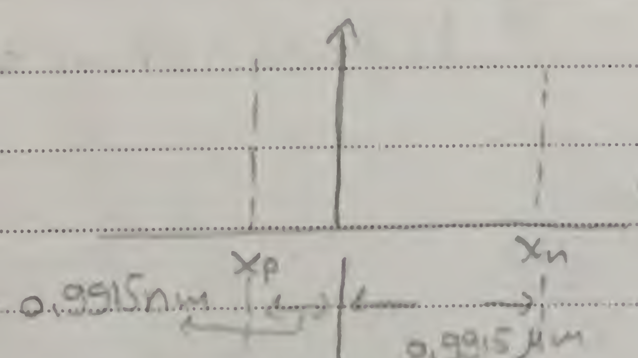
Determine ϕ_0, x_d, $|x_p|$, $|x_n|$, $\mathcal{E}_m$, Q_j, C_j @ no bias

$V_T \cong 26\,mV$

$$\phi_0 = V_T \ln \frac{N_A N_D}{n_i^2} = 26 \ln \frac{10^{11}}{2.25} = 637\,mV$$

$$x_d = \sqrt{\frac{2\epsilon\phi_0}{N_I}} \cong 0.9925\,\mu m$$

$|x_n| = 0.9915\,\mu m$, $|x_p| = 0.9915\,nm$



$$Q_{jo} = \sqrt{2\epsilon q N_I}\,\sqrt{\phi_0} = 15.8\,nC/cm^2$$

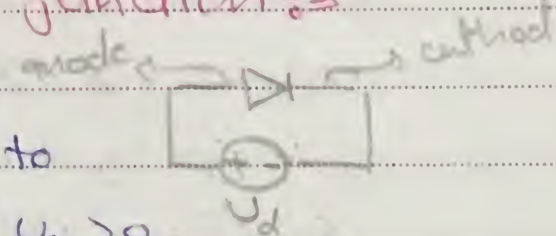
$$C_{jo} = \sqrt{\frac{\epsilon q N_I}{2}}\,\frac{1}{\sqrt{\phi_0}} = 10.47\,nF/cm^2$$

$\mathcal{E}_m = -1.525 \times 10^4 \ V/cm$

The Biased p-n junction :-

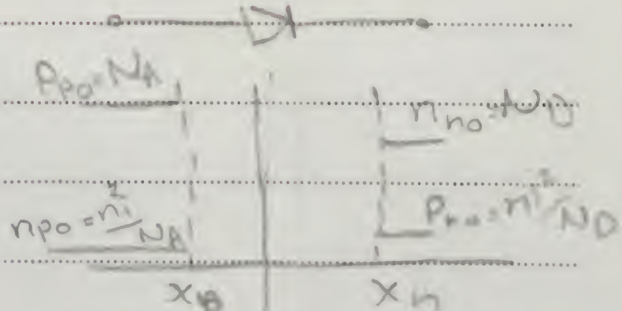
الانحياز الأمامي

- A pn junction is said to be forward Bias if $V_D > 0$.
- A pn junction is said to be reverse Biased if $V_D < 0$. (عكسي)



for open circuit pn junction :-

$$\left.\begin{aligned} P_{no} &= P_{p_o} e^{-\phi_o/V_T} \\ n_{p_o} &= n_{n_o} e^{-\phi_o/V_T} \end{aligned}\right\} \text{neutral region}$$



for $x_p \le n \le x_n$: $p_n(x) = P_{p_o} e^{-\phi(x)/V_T}$, $n_p(x) = n_{n_o} e^{-\phi(x)/V_T}$

for a reverse biased pn junction ($V_D < 0$) :-

Depletion region widens (يتوسع), barrier potential ϕ increases ($\phi = \phi_o - V_D$)

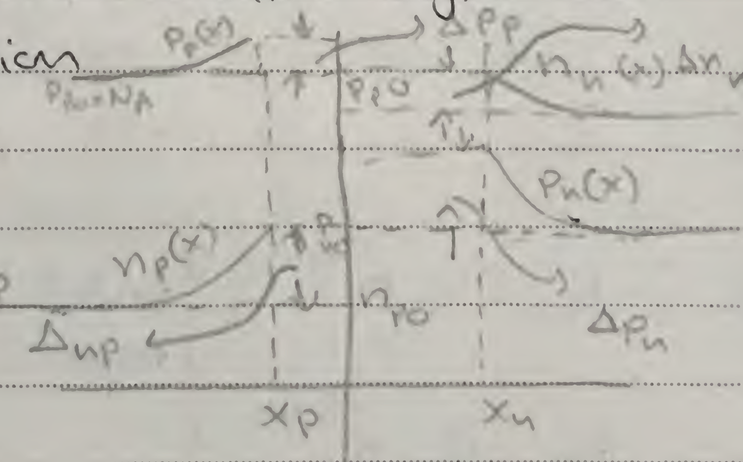
⇒ Diffusion of majority carriers become more difficult

The forward biased pn junction ($V_D > 0$)

Depletion region يتقلص shrinks, barrier potential reduce ($\phi = \phi_0 - V_D$)

⇒ majority carrier diffuse across the junction easier

⇒ concentration of minority carriers increase in the neutral Region near the junction



But to main charge neutrality, in the neutral region, The concentration of majority must increase by the same amount

$\Delta P_p(x) = \Delta n_p(x)$, $\Delta n_n(x) = \Delta P_n(x)$

$\phi_0 = -V_T \ln\left(\frac{p_{no}}{p_{po}}\right) = -V_T \ln\left(\frac{n_{po}}{n_{no}}\right)$

$$P_{no} = P_{po}\, e^{-\phi_o/V_T} \quad , \quad n_{po} = n_{no}\, e^{-\phi_o/V_T}$$

with applied Biased V_D

$$\phi_o \longrightarrow \phi = \phi_o - V_D$$

$$P_n(o) = P_p(o)\, e^{-(\phi_o - V_D)/V_T} \quad , \quad n_p(o) = n_n(o)\, e^{-(\phi_o - V_D)/V_T}$$

$$P_n(x_n) = P_p(x_p)\, e^{-(\phi_o - V_D)/V_T} \quad , \quad n_p(x_p) = n_n(x_n)\, e^{-\frac{(\phi_o - V_D)}{V_T}}$$

$$\frac{P_n(x_n)}{P_{no}} \gg \frac{n_n(x_n)}{n_{no}}$$

صفي الاول

$$\frac{n_p(x_p)}{n_{po}} \gg \frac{P_p(x_p)}{P_{po}}$$

we assume : $P_p(x_p) \cong P_{po}$, $n_n(x_n) \cong n_{no}$

$\Rightarrow$ The law of the junction :-

$$P_n(x_n) = P_{po}\, e^{-(\phi_o - V_D)/V_T} = \underbrace{P_{po}\, e^{-\phi_o/V_T}}\, e^{V_D/V_T} = P_{no}\, e^{V_D/V_T}$$

$$P_{no} = P_{po}\, e^{-\phi_o/V_T}$$

Subject: .... / /

any additional carrier concentration from that of neutral region away from the junction considered "Excess" فائض

$p'_n(x) = p_n(x) - p_{no}$ = Excess hole concentration in the n-type @ x

$n'_n(x) = n_n(x) - n_{no}$ = ... electron ...

$n'_p(x) = n_p(x) - n_{po}$ = ... h ... p-type ...

$p'_p(x) = p_p(x) - n_{po}$ = ... holes ...

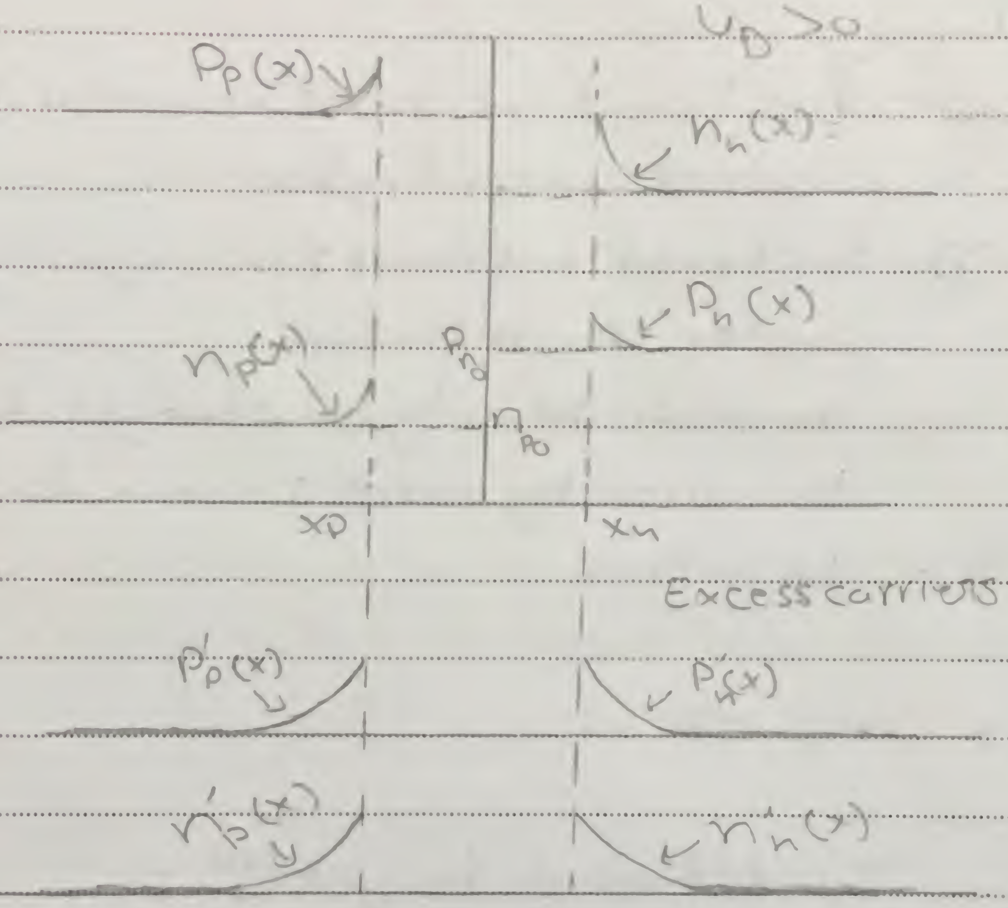
$p_{po} \gg n_{po}$, $n_{no} \gg p_{no}$, $p'_n(x) = n'_n(x)$

$n'_p(x) = p'_p(x)$

$$\Rightarrow \frac{p'_n(x)}{p_{no}} \gg \frac{n'_n(x)}{n_{no}} , \quad \frac{n'_p(x)}{n_{po}} \gg \frac{p'_p(x)}{p_{po}}$$

187 → 210
225 → 231

4/4/2017



$p'_n(x_n) = p_n(0)\, e^{V_D/V_T}$, $n'_p(x_p) = n_{p0}\, e^{V_D/V_T}$

$p'_n(x) = n'_n(x)$, $n'_p(x) = p'_p(x)$ ← to maintain charge neutrality

$p_{p0} \gg n_{p0}$, $n_{n0} \gg p_{n0}$

$$\frac{p'_n(x)}{p_{no}} \gg \frac{n'_n(x)}{n_{no}} \quad , \quad \frac{n'_p(x)}{n_{po}} \gg \frac{p'_p(x)}{p_{po}}$$

∴ ⇒ fractional increase in minority carrier concentration
≫ fractional increases in majority carrier concentration

* ⇒ concentrate only on changes due to minority carriers concentration

الإختلاف <- variation

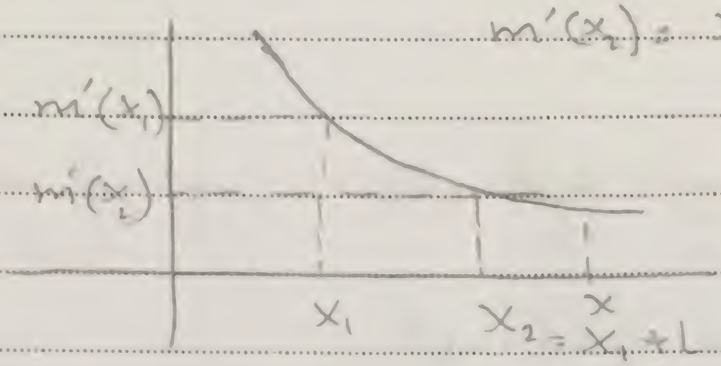
* Definitions :-

- The diffusion lenght (L) :-

In diffusion length The concentration of minority carriers is $\frac{1}{e} \cong 0.37$ of it's original value. (due to recombination)

$n'(x)$ = Excess minority carrier concentration

$n'(x_2) = \frac{n'(x_1)}{e} \simeq 0.37\, n'(x_1)$



for any x: $n'(x) = n'(x_1)\, e^{-(x-x_1)/L}$

$\Rightarrow P'_n(x) = P'_n(x_n)\, e^{-(x-x_n)/L} \quad , x \geq x_n > 0$

$n'_p(x) = n'_p(x_p)\, e^{(x-x_p)/L} \quad , x \leq x_p < 0$

– Excess minority carrier life (τ) :-

also called The mean recombination Time

longer(L) $\Rightarrow$ longer (τ)

$D = \frac{L^2}{\tau} \quad \frac{cm^2}{s} \quad (m^2/s)$

In the neutral n-region $\Rightarrow D_p = \frac{L_p^2}{\tau_p}$

" " " p-region $\Rightarrow D_n = \frac{L_n^2}{\tau_n}$

In Si typical values L_p, L_n $1 \rightarrow 100\,\mu m$

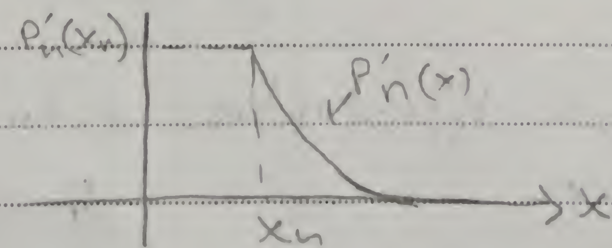
& τ_p, τ_n $10\,ns \rightarrow 1\,\mu s$

افتراض   مثالي

* Simplifying assumptions :- "to derive ideal diode equation"

1- Junction is abrupt
2- All V_0 appears across the junction
3- current flow is in one direction
4- $\mathcal{E} = 0$ in the neutral region
5- No net generation or recombination in the Depletion Region
6- low level injection : حقن
concentration of minority carriers >> concentration of majority carriers

$\mathcal{E}_0 = 0$ in neutral region ⇒ No drift current in neutral regions.
Concentration in neutral n-region:-
There is concentration gradiant of Excess minority carriers
⇒ There is whole diffusion current.



$$J_p(x_n) = -q D_p \frac{dP_n(x)}{dx}\Big|_{x=x_n}$$

$$\frac{dP_n(x)}{dx} = \frac{d}{dx}\left[P_n'(x) + P_{n0}\right] = \frac{dP_n'(x)}{dx}$$

$$= \frac{d}{dx}\left[P_n'(x_n)\, e^{-(x-x_n)/L_p}\right] \cong \frac{d}{dx}\left[P_n'(x_n)\, e^{-x/L_p}\right]$$

$$x_n \cong 0$$

$$P_n'(x) = P_n'(x_n)\, e^{-x/L_p} = \left(P_n(x_n) - P_{n0}\right) e^{-x/L_p}$$

$$P_n(x_n) = P_{n0}\, e^{V_D/V_T} \Rightarrow P_n'(x) = \left[P_{n0}\, e^{V_D/V_T} - P_{n0}\right] e^{-\frac{x}{L}}$$

$$= P_{n0}\left[e^{V_D/V_T} - 1\right] e^{-x/L_p}$$

$$\frac{dP_n'(x)}{dx} = \frac{-P_{n0}}{L_p}\left(e^{V_D/V_T} - 1\right) e^{-x/L_p}$$

$$\frac{dP_n'(x)}{dx}\Big|_{x=x_n} = \frac{-P_{n0}}{L_p}\left(e^{V_D/V_T} - 1\right) e^{0} = \frac{-P_{n0}}{L_p}\left(e^{V_D/V_T} - 1\right)$$

$$\therefore J_p(x_n) = +\frac{q D_p P_{no}}{L_p}\left(e^{v_D/v_T} - 1\right)$$

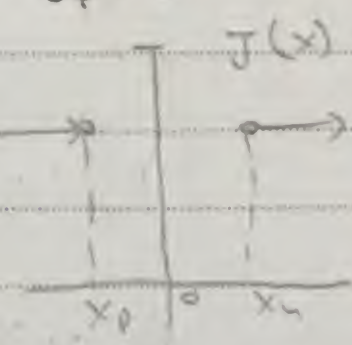
* in the neutral p-region :

The electric field current density @ x_p

in $$J_n(x_p) = \frac{q D_n n_{po}}{L_n}\left(e^{v_D/v_T} - 1\right)$$

Assumption ⑤ $\Rightarrow J_p(x_p) = J_p(x_n)$

$J_n(x_p) = J_n(x_n)$ →



$$J(0) = J_p(0) + J_n(0)$$
$$= J_p(x_p) + J_n(x_n)$$
$$= J_p(x_n) + J_n(x_p)$$

$$J(0) = \frac{q D_p P_{no}}{L_p}\left(e^{v_D/v_T} - 1\right) + \frac{q D_n n_{po}}{L_n}\left(e^{v_D/v_T} - 1\right)$$

$$J(0) = q\left[\frac{D_p P_{no}}{L_p} + \frac{D_n n_{po}}{L_n}\right]\left(e^{v_D/v_T} - 1\right)$$

$$i_D = J(0)\,A = qA\left[\frac{D_p P_{no}}{L_p} + \frac{D_n n_{po}}{L_n}\right]\left[e^{v_D/v_T} - 1\right]$$

$$\Rightarrow I_s\left(e^{V_D/V_T}-1\right)$$

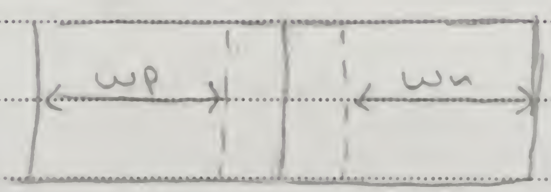
تيار الاشباع العكسي

$I_s \triangleq$ Reverse saturation current

$$= qA\left[\frac{D_p P_{no}}{L_p} + \frac{D_n n_{po}}{L_n}\right]$$

Actual expression for I_s (more accurate)

$$I_s = qA\left[\frac{D_p P_{no}}{L_p}\coth\left(\frac{W_n}{L_p}\right) + \frac{D_n n_{po}}{L_n}\coth\left(\frac{W_p}{L_n}\right)\right]$$



$$P_{no} = \frac{n_i^2}{N_D}, \quad n_{po} = \frac{n_i^2}{N_A}, \quad D = \frac{L^2}{\tau}$$

$$\therefore I_s = qA\left[\frac{L_p P_{no}}{\tau_p}\coth\left(\frac{W_n}{L_p}\right) + \frac{L_n n_{po}}{\tau_n}\coth\left(\frac{W_p}{L_n}\right)\right]$$

$$= qA n_i^2\left[\frac{L_p}{\tau_p N_D}\coth\left(\frac{W_n}{L_p}\right) + \frac{L_n}{\tau_n N_A}\coth\left(\frac{W_p}{L_n}\right)\right]$$

Reminder :-

$$\coth(y) = \frac{e^{y} + e^{-y}}{e^{y} - e^{-y}}$$

coth → البسط ميشو واحد

for $y > 2 \Rightarrow e^{-y} \cong 0 \cong \coth y \cong 1$ long base

for $y \ll 1 \Rightarrow e^{y} \cong 1 + y \,,\; e^{-y} \cong 1 - y$ short base

اقل بكتير من width

$$\Rightarrow \coth(y) \cong \frac{2}{2y} = \frac{1}{y}$$

* long base diode $(w \gg L)$

$$\Rightarrow \coth(y) \cong 1$$

$$I_s = qA\left[\frac{D_p p_{no}}{L_p} + \frac{D_n n_{po}}{L_n}\right]$$

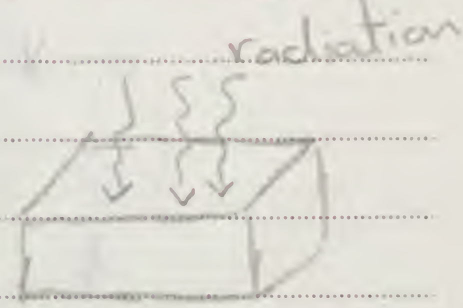
* short base diode :-

$$w \ll L \Rightarrow \coth\left(\frac{w}{L}\right) \cong \frac{L}{w}$$

$$\Rightarrow I_s = qA\left[\frac{D_p p_{no}}{w_n} + \frac{D_n n_{po}}{w_p}\right]$$

Tutorial

* solution of homework Two :-



Q5) $N_D = N_A = 10^{16} / cm^2$

after exposure

$P_{no} = 10^{13} / cm^3$

before exposure :-

$$P_{no} = \frac{n_i^2}{N_D} = \frac{2.25 \times 10^{20}}{10^{16}} = 2.25 \times 10^4$$

$$P + N_D = n + N_A \quad , \quad np = n_i^2$$

$$\frac{n_i^2}{n} + N_D = n + N_A$$

$$n_i^2 + nN_D = n^2 + nN_A$$

$$n^2 + n(N_A - N_D) - n_i^2 = 0$$

Subject: .... / /

$$n = \frac{(N_D - N_A) + \sqrt{(N_A - N_D)^2 + 4n_i^2}}{2}$$

$$p = \frac{\sqrt{(N_A - N_D) + \sqrt{(N_A - N_D)^2 + 4n_i^2}}}{2}$$

for n-type material

$$N_A = 0 \Rightarrow n = \frac{N_D + \sqrt{N_D^2 + 4n_i^2}}{2} = N_D$$

for p-type material

$$N_D = 0 \Rightarrow n = N_A$$

$$p_{n0} = \frac{n_i^2}{N_D} \Rightarrow n_i = \sqrt{N_D\, p_{n0}}$$

Q3

$$\phi_0 = V_T \ln \frac{N_A N_D}{n_i^2},$$

$$n_i = n_i(290 K^{\circ})$$

find T such $\phi_0(T) = \phi_0(290) - 0.04\phi_0(290)$

$$d\phi_0 = -0.04\,\phi_0(290)\,dT$$

$$\frac{d\phi_0}{dT} = -0.04\,\phi_0(290)$$

$$\frac{d\phi_0}{dT} = \frac{\phi_0 - V_g}{T} + \frac{dV_g}{dT} - \frac{3k}{q}$$

$$E_g = q V_g = 0.67\,eV \Rightarrow V_g = \frac{0.67}{1e} = 0.67\,V$$

$$\frac{dE_g}{dT} = 0 \Rightarrow \frac{dV_g}{dt}$$

$$\frac{d\phi_0}{dT} = \frac{\phi_0 - 0.67}{290} - x$$

Subject:

/ /

$$\frac{-0.04\phi_0}{dT} = \frac{\phi_0 - 0.67}{290} - x$$

Q2) a// $\phi_0 = V_T \ln \frac{N_A N_D}{(n_i)^2}$

$$n_i = k_1 T^{3/2} e^{-E_g/kT}$$

$$\frac{dV_T}{dT}$$

$$\frac{d\phi_0}{dT} = V_T \frac{d}{dT}\left[\ln \frac{N_A N_D}{(n_i)^2} + \ln \frac{N_A N_D}{(n_i)^2}\right]$$

$$\frac{dV_T}{dT} = \frac{d}{dT}\left(\frac{k_B T}{q}\right) = \frac{k_B}{q} = \frac{V_T}{T}$$

$\ln x = \frac{1}{x}$

$\ln y = \frac{1}{y}\frac{dy}{dx}$

$$\frac{d}{dT}\left[\ln \frac{N_A N_D}{(n_i)^2}\right] = \frac{n_i^2}{N_A N_D}\frac{d}{dT}\frac{N_A N_D}{(n_i)^2}$$

$$\frac{d}{dT}\left(\overbrace{\frac{N_A N_D}{n_i^2}}^{X}\right)$$

Subject: .... / /

$$\frac{dx}{dT} = \frac{dx}{dn_i}\,\frac{dn_i}{dT}$$

$$\frac{dx}{dn_i} = \frac{d}{dn_i}\left(N_A N_D n_i^{-2}\right) = \frac{-2N_A N_D}{n_i^{3}}$$

$$\frac{dn_i}{dT} = \underbrace{k_1 T^{\frac{3}{2}} e^{-E_g/k_B T}}_{n_i}\;\frac{d}{dT}\left(\frac{-E_g}{k_B T}\right)$$

$$\frac{d}{dT}\left(\frac{-E_g}{k_B T}\right) = \frac{-d}{dT}\left(\frac{qV_g}{k_B T}\right)$$

$$= \frac{-q}{k_B}\,\frac{d}{dT}\left(\frac{V_g}{T}\right) = \frac{-q}{K_B}\left(\frac{T\frac{dV_g}{dT} - V_g}{T^2}\right)$$

$$\frac{dx}{dt} = +\frac{2N_D N_A}{n_i^{3}}\,\frac{q}{k_B}\left(\frac{T\frac{dV_g}{dT} - V_g}{T^2}\right)$$

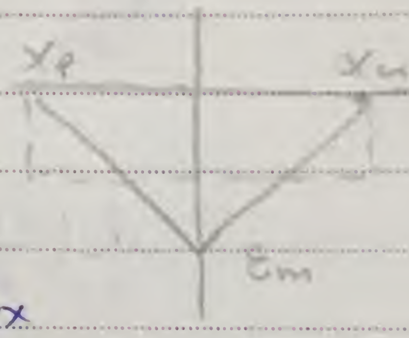
$$\frac{d}{dT}\left(\ln\frac{N_A N_D}{n_i^{2}}\right) = \frac{n_i^2}{N_A N_D} * \frac{2N_D N_A}{n_i^3}\,\frac{q}{k_B}\left(\frac{T\frac{dV_g}{dT} - V_g}{T^2}\right)$$

Subject: .... / /

$$= \frac{2qn_i^2}{k_B T^2}\left(T\frac{dv_g}{dT} - v_g\right)$$

فيه خطأ لكن نفس الفكرة مهمش
بيها

Q4) a//



$$\bar{\mathcal{E}}_m = \frac{1}{x_d}\int_{x_p}^{x_n} \mathcal{E}(x)\,dx$$

$$= \left[\frac{1}{2}x_d\,\mathcal{E}_m\right] * \frac{1}{x_d}$$

$$\Rightarrow \;= \frac{1}{2}\mathcal{E}_m$$

8/4/2017

Q2) a-

Show that $\dfrac{d\phi}{dT} = \dfrac{\phi_0 - V_g}{T} + \dfrac{dV_g}{dT} - \dfrac{3k_B}{q}$

$$\phi_0 = V_T \ln \frac{N_A N_D}{(n_i)^2}, \quad n_i = K_1 T^{\frac{3}{2}} e^{-E_g/2k_BT}$$

$$\frac{d\phi_0}{dT} = \ln\left[\frac{N_A N_D}{(n_i)^2}\right]\frac{dV_T}{dT} + V_T \frac{d}{dT}\left[\ln \frac{N_A N_D}{(n_i)^2}\right]$$

$$\ln\left[\frac{N_A N_D}{(n_i)^2}\right] = \ln N_A N_D - \ln n_i^2$$

$$= \ln N_A N_D - 2\ln n_i$$

$$\frac{dV_T}{dT} = \frac{k_B}{q} = \frac{V_T}{T}$$

$$\Rightarrow \frac{d}{dT}\ln\left(\frac{N_A N_D}{n_i^2}\right) = \frac{-2}{n_i}\frac{dn_i}{dT}$$

$$\frac{d}{dT}\ln\left(\frac{N_A N_D}{(n_i)^2}\right) = \frac{(n_i)^2}{N_A N_D}\frac{d}{dT}\left[\frac{N_A N_D}{(n_i)^2}\right]$$

$$= \frac{(n_i)^2}{N_A N_D}\left[\frac{-2N_A N_D n_i}{n_i^4}\right]\frac{dn_i}{dT} = \frac{-2}{n_i}\frac{dn_i}{dT}$$

$$\frac{dn_i}{dT} = \frac{3}{2} k_1 T^{\frac{1}{2}} e^{\frac{-E_g}{2k_BT}} + k_1 T^{\frac{3}{2}} e^{-E_g/2k_BT} \frac{d}{dT}\left(\frac{-E_g}{2k_BT}\right)$$

$$= \frac{3/2\, n_i}{T} + n_i \frac{d}{dT}\left(\frac{-E_g}{2k_BT}\right) = n_i \left[\frac{3/2}{T} - \frac{d}{dT}\left(\frac{E_g}{2k_BT}\right)\right]$$

$$\frac{d}{dT}\left(\frac{E_g}{2k_BT}\right) = \frac{2k_BT \frac{dE_g}{dT} - 2k_B E_g}{4k_B^2 T^2}$$

$$= \frac{T \frac{dE_g}{dT} - E_g}{2k_B T^2}$$

$$E_g = qU_g \Rightarrow \frac{dE_g}{dT} = q\frac{dU_g}{dT}$$

$$\Rightarrow \frac{d}{dT}\left(\frac{E_g}{2k_BT}\right) = \frac{qT \frac{dU_g}{dT} - qU_g}{2k_B T^2}$$

$$= \frac{q\left(T \frac{dU_g}{dT} - U_g\right)}{2k_B T^2}$$

Subject: / /

$$\Rightarrow \frac{d}{dT} \ln \frac{N_A N_D}{n_i^2} = \frac{-2}{n_i} n_i \left[\frac{3/2}{T} - \frac{q\left(T \frac{dV_g}{dT} - V_g\right)}{2 k_B T^2} \right]$$

$$= \frac{-2}{T} \left[3/2 - \frac{q\left(T \frac{dV_g}{dT} - V_g\right)}{2 k_B T} \right]$$

$$\Rightarrow \frac{d\phi_0}{dT} = \frac{V_T}{T} \ln \frac{N_A N_D}{(n_i)^2} - \frac{2V_T}{T} \left[3/2 - \frac{q\left(T \frac{dV_g}{dT} - V_g\right)}{2 k_B T} \right]$$

$$= \frac{\phi_0}{T} - \frac{k_B T}{qT} \left[3 - \frac{q\left(T \frac{dV_g}{dT} - V_g\right)}{k_B T} \right]$$

$$= \frac{\phi_0}{T} - \left[\frac{3k_B}{q} - \frac{T \frac{dV_g}{dT} - V_g}{\cancel{q}\, T} \right]$$

$$\frac{d\phi_0}{dT} = \frac{\phi_0 - V_g}{T} + \frac{dV_g}{dT} - \frac{3k_B T}{q}$$

Subject: .... / /

$$\Rightarrow \frac{d}{dT}\ln\frac{N_A N_D}{n_i^2} = \frac{-2}{n_i}\, n_i\left[\frac{3/2}{T} - \frac{q\left(T\frac{dV_g}{dT} - V_g\right)}{2k_B T^2}\right]$$

$$= \frac{-2}{T}\left[3/2 - \frac{q\left(T\frac{dV_g}{dT} - V_g\right)}{2k_B T}\right]$$

$$\Rightarrow \frac{d\phi_0}{dT} = \frac{V_T}{T}\ln\frac{N_A N_D}{(n_i)^2} - \frac{2V_T}{T}\left[3/2 - \frac{q\left(T\frac{dV_g}{dT} - V_g\right)}{2k_B T}\right]$$

$$= \frac{\phi_0}{T} - \frac{k_B T}{qT}\left[3 - \frac{q\left(T\frac{dV_g}{dT} - V_g\right)}{k_B T}\right]$$

$$= \frac{\phi_0}{T} - \left[\frac{3k_B}{q} - \frac{T\frac{dV_g}{dT} - V_g}{T}\right]$$

$$\frac{d\phi_0}{dT} = \frac{\phi_0 - V_g}{T} + \frac{dV_g}{dT} - \frac{3k_B T}{q}$$

ϕ_0 تقل بزيادة درجة الحرارة

b// $N_D = 10^{14}\ /cm^3$, $N_A = 10^{18}\ /cm^3$

calculate $\frac{d\phi_0}{dT}$ @ $305°k$ & ϕ_0

$$\phi_0(305°k) = \phi_0(300°k) + d\phi_0\Big|_{T=300°k}$$

$$\phi_0(300°k) = V_T \ln \frac{N_A N_D}{(n_i)^2} \cong 25 \ln \frac{10^{32}}{2.25\times10^{20}}\ mV$$

$$= 447\,mV$$

$$d\phi_0\Big|_{300°k} = \left[\frac{\phi_0(300°k) - V_g}{T} + \frac{dV_g}{dT} - \frac{3k_B}{q}\right] dT$$

ΔT $\times 5$

$$d\phi_0\Big|_{300°k} = \frac{447 - 1120}{300} - 0.275 - \frac{3\times1.38\times10^{-23}}{1.6\times10^{-19}}$$

$$\phi_0(305°) = 434.5\,mV$$

Subject: ....

/ /

الصيحة الأولى

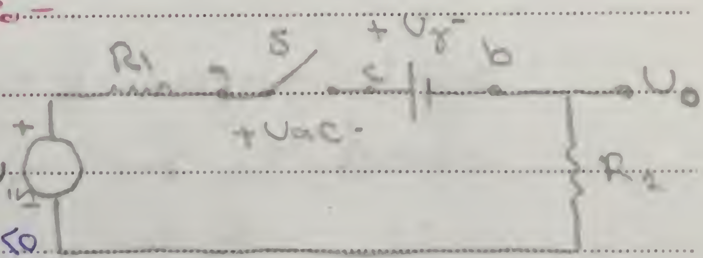
Given: $\phi_o = 447\,mV$, $\frac{d\phi_o}{dT} = -2.5\,mV/K$ @300

find T @ wich $\phi_o = 460\,mV$

as simply $\frac{d\phi_o}{dT} = 2.5\,mV/K°$, $d\phi_o = 13$

$dT = \frac{13}{-2.5} \Rightarrow T = 294.8\,K°$

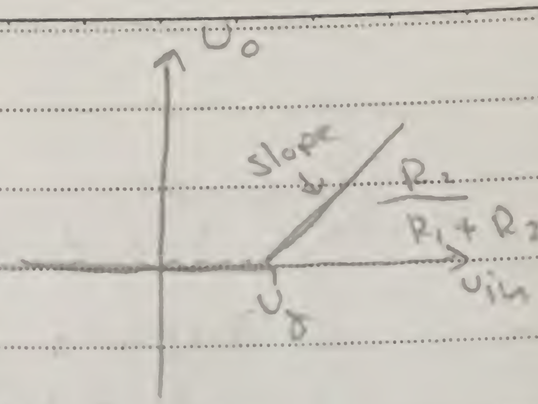
Problem set zero :-



- swich S remains open as long as $V_{ac} \le 0$
- sketch V_o as function in V_{in}

when swich S open $V_o = 0$
because $V_o = V_{R_2} = IR = 0$

when swich S closed $\Rightarrow V_o = \left(\frac{R_2}{R_1+R_2}\right)V_{in}$



S is open $\Rightarrow V_{ac}<0$

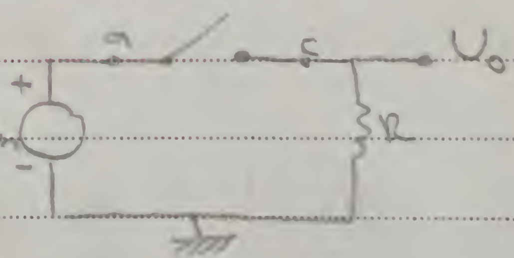
when S is open

$$V_{ac} = V_a - V_c$$
$$= V_{in} - V_\gamma$$

S is open if $V_{in} - V_\gamma < 0$

" " " " , $V_{in} < V_\gamma$

S is closed for $V_{in} \geq V_\gamma$

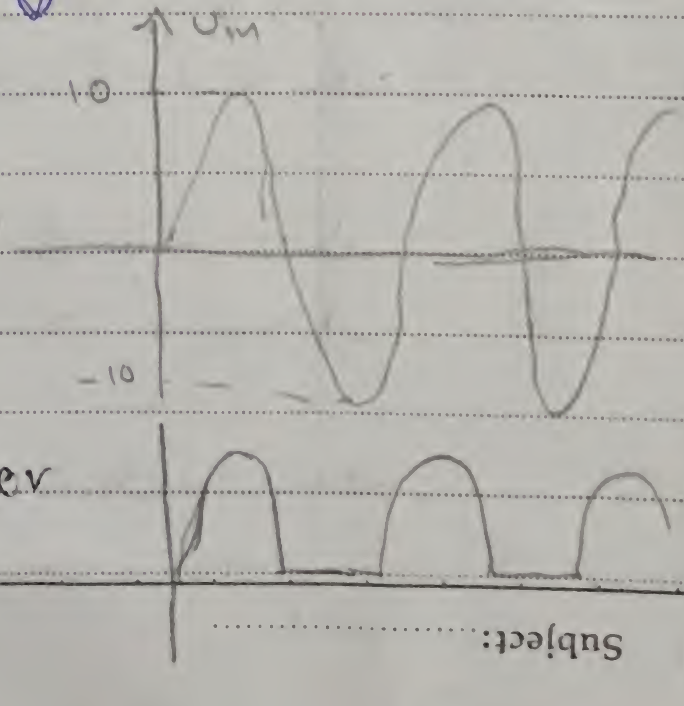


swich is open if $V_{ac}<0$

sketch V_o for

$V_{in} = 10 \sin wt$ v

$$V_o = \begin{cases} 0 & \text{for } V_{in}<0 \\ V_{in} & \text{for } V_{in} \geq 0 \end{cases}$$

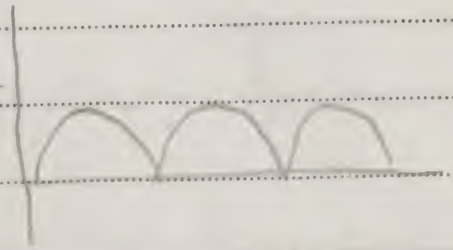


The circuit is called

Half wave Rectifier

(HWR)

full wave Rectifire



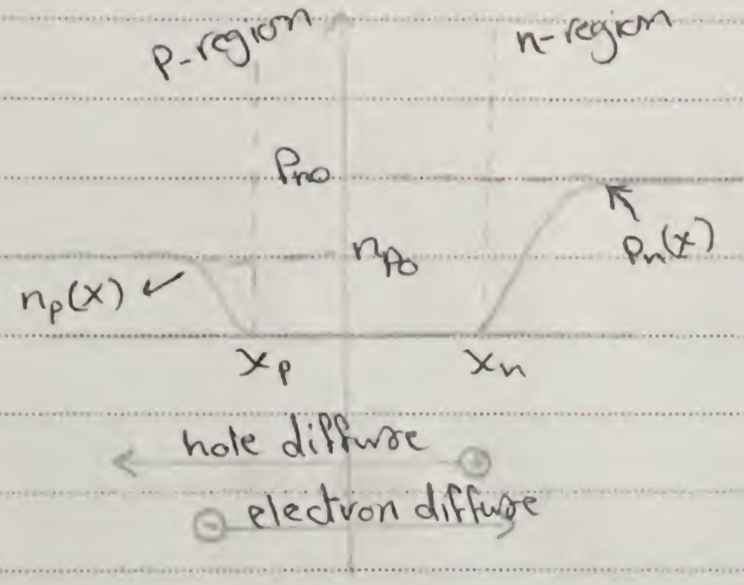
$v_o = |v_{in}|$

Test one #

Subject: / /

11/4/2017

The reverse biased p-n junction :-



from the low of the junction :-

$$P_n(x_n) = P_{n0}\, e^{V_D/V_T}$$

كل المسألة على طرفين لساير

$V_D < 0$:-

for $|V_D| \ll T$

$P_n(x_n) \cong 0$

$n_p(x_p) \cong 0$

Subject: .... / /

- from concentration gradiant of minority Carrier.

$\Rightarrow$ +ve current flows from n-region to p-region.

التيار الخارج

$(I_D < 0)$

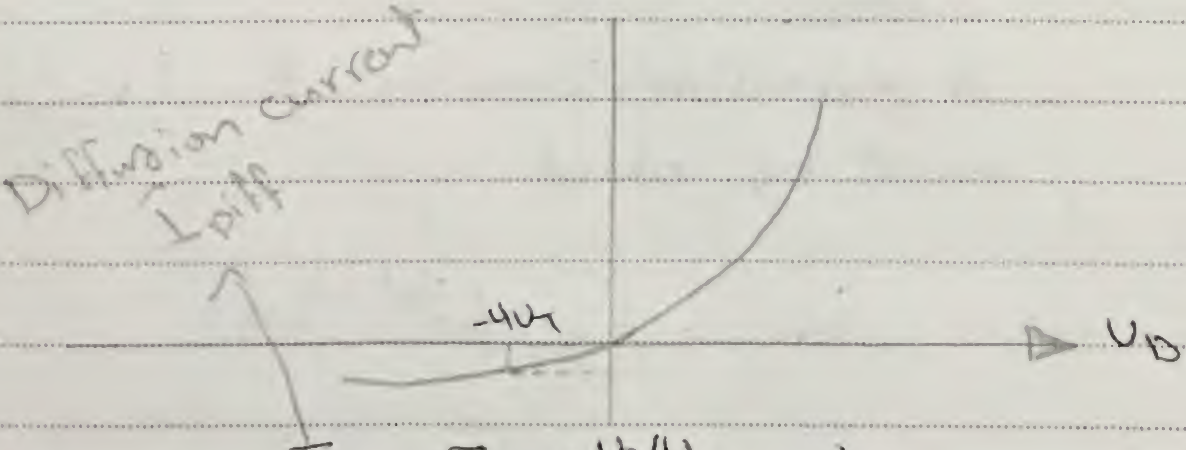
I_D is very small

for $|v_D| \ll 4V_T$ $\quad (v_D \ll -4V_T)$:-

$$e^{v_D/V_T} \ll e^{-4} \cong 0$$

$\Rightarrow$ concentration gradiant doesnt change very much in slope

$\Rightarrow$ diffusion current satuiate يتشبع



$$I_D = I_S\,(e^{v_D/V_T} - 1)$$

for $(V_D < -4V_T) \Rightarrow I_D < I_S(e^{-4} - 1) \cong I_S$

امتحانات عليه

- Practical considerations :-

1- measured values of I_D with reverse biased is much greater than computes by the formula $|I_D| \gg |I_S|$

2- under forward biased ... of the carriers injected in the depletion region recombine given rise

يعطي الصعود

اعادة تركيب

a recombination current that must be added.

- under reverse biased injected in The depletion region give rise to

توليد, مرئ

generation current that must be added.

- A generation - Recombination (i_{rg}) must be added

$$i_{rg} = I_{RO}\left(e^{V_D/V_T\gamma} - 1\right)$$

$$I_{RO} = \frac{qAn_iX_d}{2\tau_o}$$

/ /

Subject: ....

$\tau_o = \tau_{po} = \tau_{no}$ effictive life time of carrier in the deplation region

for $U_D < -4U_T$

$\Rightarrow I_{rg} \cong -I_{RO}$

$\Rightarrow I_D = I_{Diff} + I_{rg}$

$\Rightarrow I_D = I_s(e^{U_D/U_T} - 1) + I_{RO}(e^{U_D/2U_T} - 1)$

- for a reverse biased p-n junction ($8 U_D < -4 U_T$)

3- There is surface leakage current ($\sim 1nA$) should be added

* since are one the current components daurates the other

$\Rightarrow I_D = I_o(e^{U_D/\eta U_T} - 1)$

if $I_{Diff} \gg I_{rg} \Rightarrow I_o = I_s$ & $\eta = 1$

if $I_{rg} \gg i_{Diff} \Rightarrow I_o = I_{Ro}$ & $\eta = 2$

- Notes:-

① $I_s \propto n_i^2$, $I_{ro} \propto n_i$

② $e^{V_D/V_T} \gg e^{V_D/2V_T}$ for $V_D > 0.1$

③ n_i for Ge is much larger than n_i for Si & GaAs

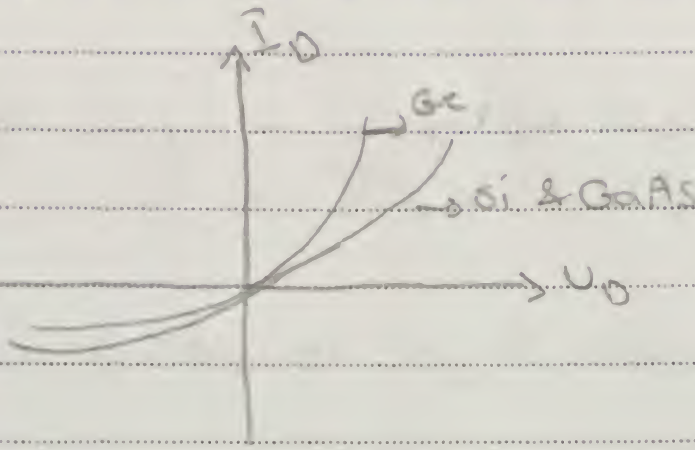
④ n_i increases with tempreture

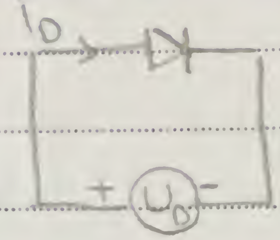
$\Rightarrow$ $I_s \gg I_{Ro}$ @ high tempreture even if n_i is small

$\Rightarrow$ $I_{RG} \gg I_s$ @ very low tempreture even if n_i is large

- In most cases ($i_{Diff} \gg i_{rg}$) except for Si & GaAs @ low tempreture & reverse biased and for Ge @ low

temprature & small for reverse biased





with reverse biased a very small (-ve) current I_D flows

⇒ Diode allows current to flow in only one direction

* Temprature effect :-

$$I_D = I_o \left(e^{V_D/nV_T} - 1 \right)$$

① $I_o = I_s$ or I_{Ro} , $I_s \propto n_i^2$, $I_{Ro} \propto n_i$
(n_i) increase with temprature

② The Thermal voltage ($V_T = \frac{k_B T}{q}$) linearly increases with Temprature

الإشتقاق

- Dependance of I_s on T :-

$$I_s = K_1 n_i^2$$

$$n_i(T) = K_2 T^{\frac{3}{2}} e^{-\frac{\alpha}{T}} \quad \alpha \rightarrow \frac{E_g}{2K_B}$$

ثابتة E_g إذا assume E_g is tempreture independent

$$\frac{dI_s}{dT} = 2K_1 n_i \frac{dn_i}{dT}$$

$$\frac{dn_i}{dT} = \frac{3}{2} K_2 T^{\frac{1}{2}} e^{-\frac{\alpha}{T}} - \alpha K_2 T^{\frac{3}{2}} e^{-\frac{\alpha}{T}} \frac{d}{dT}\frac{1}{T}$$

$$= 2K_1 n_i \left[\frac{3/2\, n_i}{T} + \frac{\alpha n_i}{T^2} \right]$$

$$= 2 \frac{K_1 n_i^2}{T} \left[\frac{3}{2} + \frac{\alpha}{T} \right] = \frac{2I_s}{T} \left[\frac{3}{2} + \frac{\alpha}{T} \right]$$

$$\frac{dI_s/dT}{I_s} = \frac{1}{T} \left[3 + \frac{2\alpha}{T} \right]$$

$$@\ 300^\circ K \Rightarrow \frac{dI_s/dT}{I_s} = \begin{cases} \frac{1}{300}\left[3 + \frac{1400}{300}\right] \\ \cong 0.16 \text{ for Si} \\ \frac{1}{3}\left[3 + \frac{1900}{300}\right] \\ \cong 0.11 \text{ for Ge} \end{cases}$$

what is dT that makes I_s doubles ?!

for Ge $(0.11)^{dT} = 2$

$dT = \ln\left(\frac{2}{0.11}\right) \cong 7^\circ$

for Si $(0.16)^{dT} = 2$

$dT = \ln\left(\frac{2}{0.16}\right) = 5^\circ C$

$\downarrow$ عملي

Practical (8°)

11/4/2017

معامل درجة الحرارة

* Temprature cofficiant of I_D for fixed V_D :-

- for a forward biased diode :-

$$I_D = I_s \left(e^{V_D/V_T} - 1\right) \cong e^{V_D/V_T} \cdot I_s$$

$$\left[\frac{dI_D/dT}{I_D}\right] = \frac{1}{I_D}\frac{d}{dT}\left[I_s e^{V_D/V_T}\right]$$

$$= \frac{1}{I_D}\left[\frac{dI_s}{dT} e^{V_D/V_T} + I_s \frac{d}{dT} e^{V_D/V_T}\right]$$

$$= \frac{e^{V_D/V_T}}{I_D}\frac{dI_s}{dT} + \frac{I_s}{I_D}\left[e^{V_D/V_T}\frac{d}{dT}\left(\frac{V_D}{V_T}\right)\right]$$

$$V_T = \frac{K_B T}{q}$$

Subject: ....

/ /

The continue of lecture

is after the next lecture

" after the lecture of Date 29/4 "

when u will study u should

follow the original sequince

Subject:

29/4/2017

* Application of Diode (Diode circuit):-

Diode is nonlinear ckt element

$$i_D = i_s (e^{v_D/V_T} - 1)$$

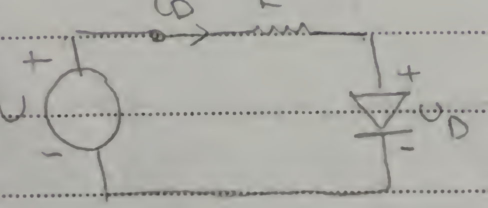
⇒ Exact solution requires solving nonlinear eqns

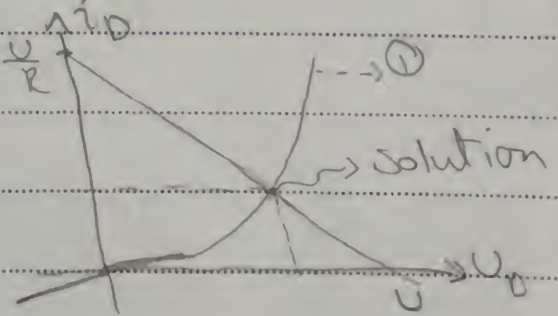
- practically, you can estimate approximate solution, by modeling the Diode as a piece wise linear ckt element.

I) Exact solution (Example):-

For the Diode: $i_D = I_s (e^{v_D/V_T} - 1)$ ---> (1)

load line eqn $i_D = \frac{V - v_D}{R}$ ---> (2)





Newton's methods to solve non linear ~~solution~~ :- eqn

find x for wich $f(x)=0$

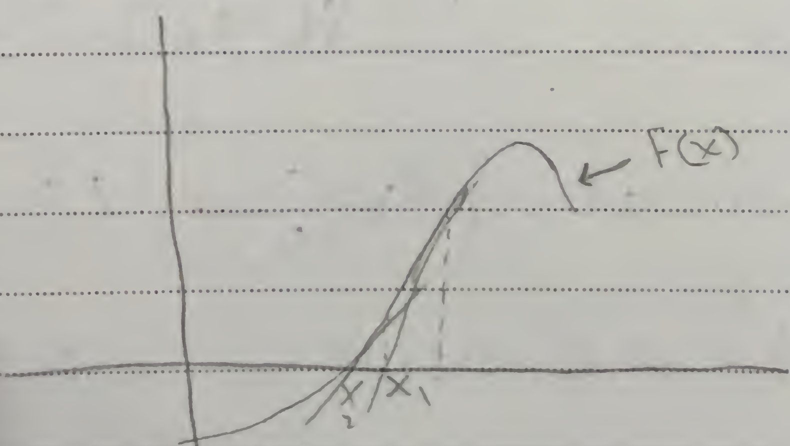
Expansion of $f(x)$ about x_0

$$f(x) = \sum_{n=0}^{\infty} \frac{(x-x_0)^n f^{(n)}(x_0)}{n!}$$

$$= f(x_0) + (x-x_0) f'(x_0) + \frac{(x-x_0)^2}{2} f''(x) + \cdots$$

Assume $f(x)$ is linear in region very close to x_0

$$\Rightarrow f(x) \cong \underbrace{f(x_0) + (x-x_0) f'(x_0)}_{g(x)}$$



$$f(x) = f(x_0) - (x - x_0) f'(x_0) = 0$$

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)}$$

$$x_2 = x_1 - \frac{f(x_1)}{f'(x_1)}$$

* Algorithm :-

① initial gun x_0

② Iterate the

$$x_k = x_{k-1} - \frac{f(x_{k-1})}{f'(x_{k-1})} \quad , k = 1, 2, 3$$

③ stop if $\left| \frac{f(x_k) - f(x_{k-1})}{f(x_{k-1})} \right| < \varepsilon \quad [\varepsilon = 1 \times 10^{-6}]$

or $\left| \frac{x_k - x_{k-1}}{x_{k-1}} \right| < \varepsilon$

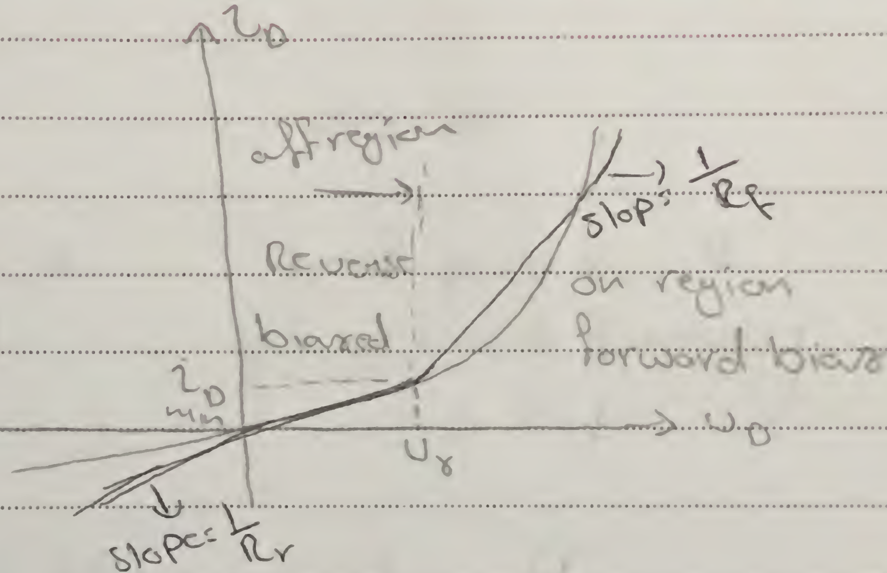
* for the diode circuit :-

$$f(V_D) = ① - ②$$

$$f(V_D) = I_s \left(e^{V_D/V_T} - 1 \right) - \frac{V - V_D}{R}$$

$$f'(v_D) = \frac{I_s e^{v_D/v_T}}{v_T} + \frac{1}{R}$$

* Piece-wise linear model of diode :-



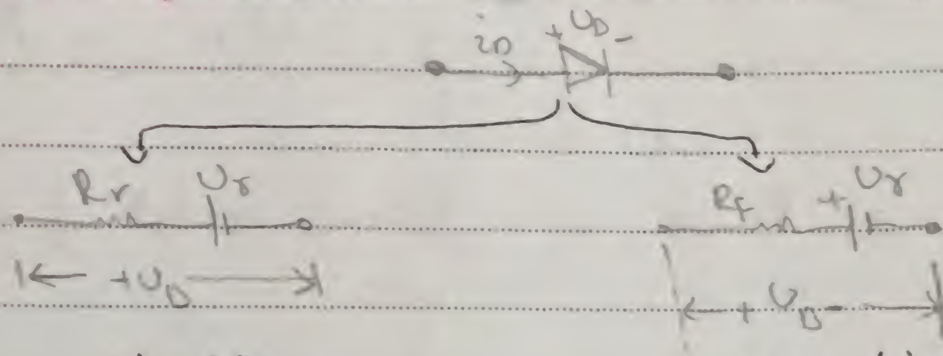
- assume diode is on if a minimum forward current $i_{D\,min}$. v_γ is called The cut-in voltage.

i.e Diode is forward biased if $v_D > v_\gamma$
& reverse biased if $v_D < v_\gamma$

- for $v_D < v_\gamma$, approximate the charact

-

model one :-



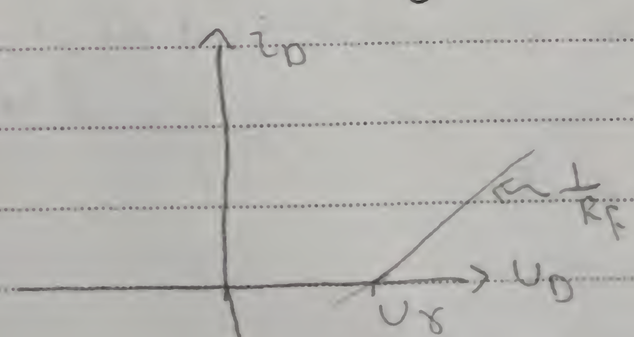
$v_D < V_\gamma$ $\qquad$ $v_D \geq V_\gamma$

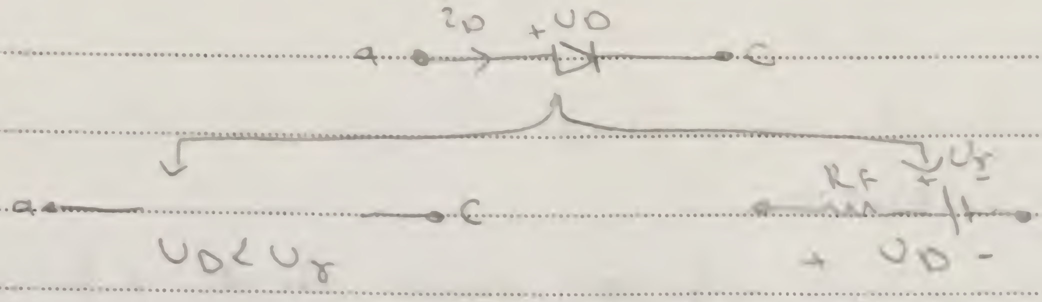
R_r is very large (several 10's or 100's of $k\Omega$) $\qquad$ R_f is very small (few 10's of Ω)

V_γ : (0.5 → 0.75 for Si diodes)
: (0.15 → 0.25 for Ge diodes)

model Two :-

R_r is larg (assum $R_r = \infty$)





Subject:........................ / /

Analyzing Diode circuits :-

Notes -

- if you assume diode is forward biased you must get $i_D \geq 0$
- if you assume diode is reverse biased, you must get $v_D < V_\gamma$

Example :-

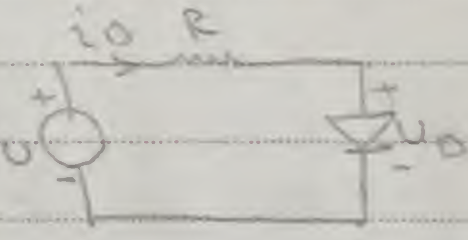
Determine i_D, v_D

$R = 10 K\Omega$, $V_\gamma = 0.7V$

$R_f = 0.1 K\Omega$, $R_r = \infty$

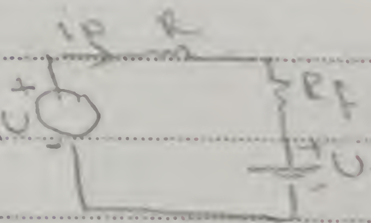
for a// $V = 0.2V$

b// $V = 5V$



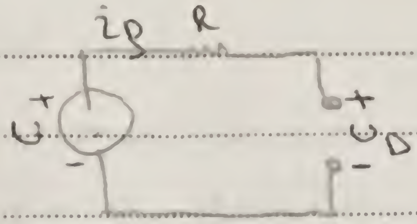
a// assume diode is forward biased

$$i_D = \frac{V - V_\gamma}{R + R_f} = \frac{0.2 - 0.7}{10.1} = \frac{-0.5}{10.1} \text{ mA}$$



the assumption is wrong Diode is off

$i_D = 0 \Rightarrow U_D = U = 0.2\,V$



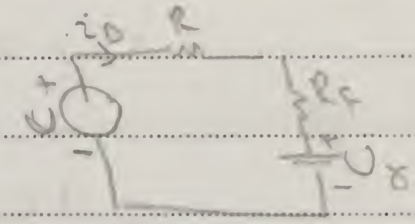
b// Assume diode is off

$i_D = 0 \Rightarrow U_D = U = 5U$

$\Rightarrow U_D > U_\gamma$ assumption is wrong

$\Rightarrow$ Diode is on

$$i_D = \frac{U - U_\gamma}{R + R_f} = \frac{5 - 0.7}{10.1} = \frac{4.3}{10.1}\,mA$$



Example :-

دائرة القطع

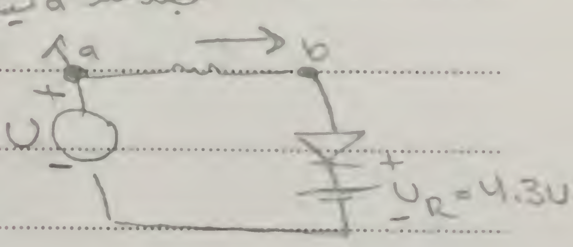
(clipping circuit)

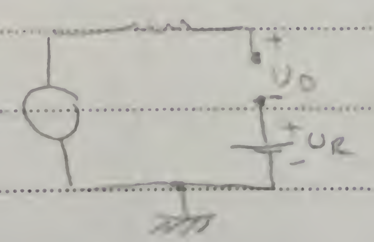
باش يكون forward لازم على الأقل الجهد عند a يساوي الجهد عند b

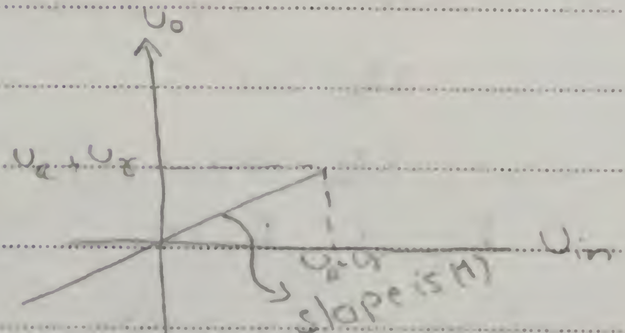
$U_\gamma = 0.7$, $R_f = 0$, $R_r = \infty$

sketch U_o reverse U_{in}

when diode is off







$V_o = V_{in}$

$V_D = V_{in} - V_R$

Diode is off as long as $V_D < V_\gamma$

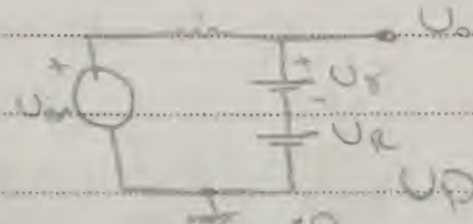
$\Rightarrow$ " " " " " " $V_{in} - V_R < V_\gamma$

$\Rightarrow$ " " " " " " $V_R + V_\gamma > V_{in}$ $(V < 5V)$

$V_o = V$ for $V_{in} < 5$

for $V_{in} \geq (V_R + V_\gamma)$, Diode is on

$V = V_R + V_\gamma$



$V_D > V$

$$V_o = \begin{cases} V_{in} & \text{for } V_{in} \leq V_R + V_\gamma \text{ (forward)} \\ V_R + V_\gamma & \text{for } V_{in} \geq V_R + V_\gamma \text{ (reverse)} \end{cases}$$

and

output is clipped @ $V_o = V_R + V_\gamma$

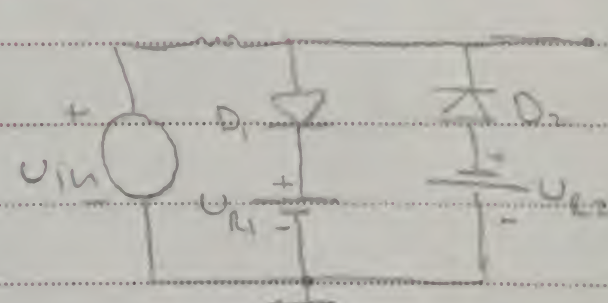
Two - way clipper :-

$V_{R_1} > 0$

$V_{R_2} > 0$

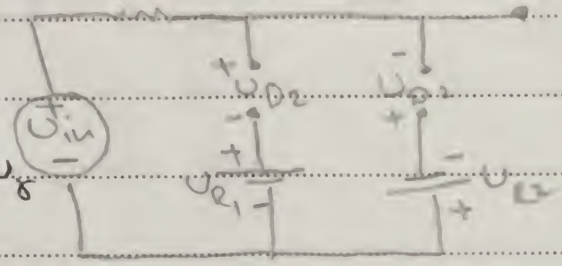
$R_f = 0$, $R_r = \infty$

$V_{\gamma 1} = V_{\gamma 2} = V_\gamma$



متشغلين الدوز الاتنين في نفس الوقت لانه لازم
يكون أكبر من V_{R1} وأقل من V_{R2} وهما الزوز
متساويين => تناقض اي حالة مستحيلة

when both diodes are off



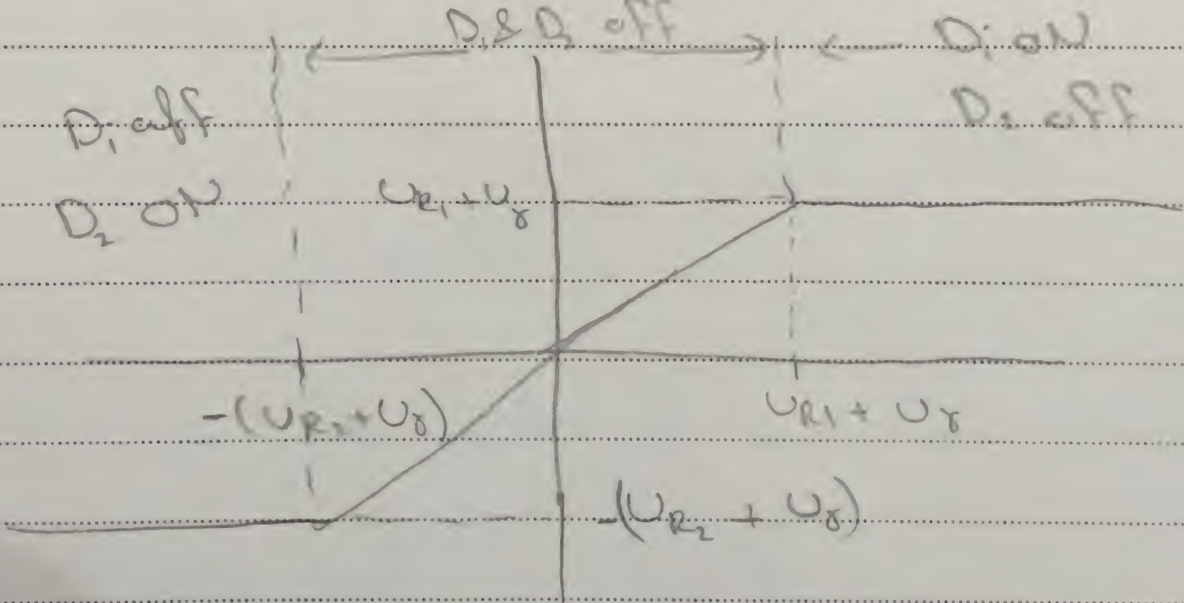
$V_o = V_{in}$

$V_{D1} = V_o - V_{R1} = V_{in} - V_{R1} < V_\gamma$

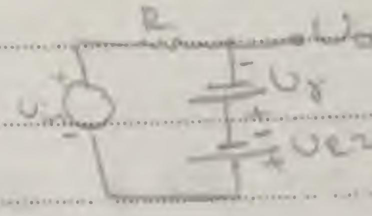
$\Rightarrow V_{in} < V_R + V_\gamma$

$V_{D2} = -V_{R2} - V_o = -V_{R2} - V_{in} < V_\gamma \Rightarrow V_{in} > -(V_{R2} + V_\gamma)$

$-(V_{R2} + V_\gamma) < V_{in} < (V_{R1} + V_\gamma)$

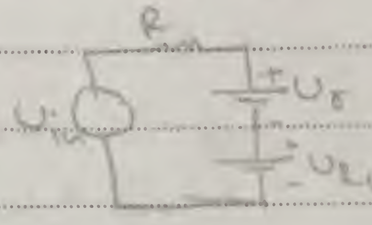


- for $v_{in} \le -(V_{R} + V_\gamma)$, D_1 off, D_2 ON



$$V_o = -(V_{R_2} + V_\gamma)$$

- for $v_{in} \ge (R_1 + V_\gamma) \Rightarrow D_1$ ON, D_2 off



$$V_o = V_{R_1} + V_\gamma$$

$$V_o = \begin{cases} -(V_{R_2} + V_\gamma) & \text{for } v_{in} \le -(V_{R_2} + V_\gamma) \\ v_{in} & \text{for } -(V_{R_2} + V_\gamma) < v_{in} < (V_{R_1} + V_\gamma) \\ (V_{R_1} + V_\gamma) & \text{for } v_{in} \ge (V_{R_1} + V_\gamma) \end{cases}$$

Subject: .... / /

11/4/2017

* The continue of lecture 11/4/2017

$$V_T = \frac{k_B T}{q}$$

$$\frac{d}{dT}\left(\frac{V_D}{V_T}\right) = \frac{-V_D \, dV_T/dT}{V_T^2} = \frac{-V_D V_T / V}{V_T^2} = \frac{-V_D}{T V_T}$$

$$\frac{dI_D/dT}{I_D} = \frac{e^{V_D/V_T}}{I_D}\frac{dI_s}{dT} - \frac{I_s V_D e^{V_D/V_T}}{I_D T V_T}$$

$$= \frac{1}{I_s}\frac{dI_s}{dT} - \frac{V_D}{T V_T} \quad \#$$

* Tempreture coefficent of V_D for fixed I_D :-

$$\left.\frac{dV_D}{dT}\right|_{\Delta I_D = 0} \quad , \quad I_D \cong I_s e^{V_D/V_T}$$

$$V_D = V_T \ln\left(\frac{I_D}{I_s}\right)$$

$$\frac{dV_D}{dT} = \frac{d}{dT}\left[V_T \ln\left(\frac{I_D}{I_s}\right)\right]$$

$$= \frac{dV_T}{dT}\ln\frac{I_D}{I_s} + V_T\frac{d}{dT}\ln\left(\frac{I_D}{I_s}\right)$$

$$= \frac{V_T}{T}\ln\frac{I_D}{I_s} + V_T\frac{I_s}{I_D}\frac{d}{dT}\left(\frac{I_D}{I_s}\right)$$

$$= \frac{V_D}{T} + \frac{V_T I_s}{I_D}\left(\frac{-I_D\, dI_s/dT}{I_s^2}\right)$$

$$\Rightarrow \frac{dV_D}{dT} = \frac{V_D}{T} - \frac{V_T}{I_s}\frac{dI_s}{dT}$$

$$= \frac{V_D}{T} - V_T\left(\frac{dI_s/dT}{I_s}\right)$$ ※

Example:-

assume I_D is constant & $V_D = 0.7V$

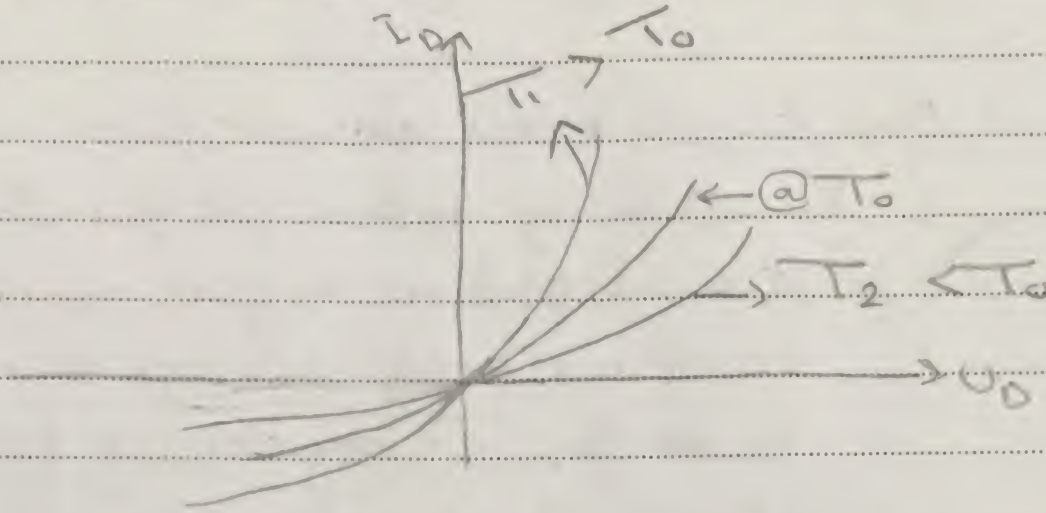
@ $300^\circ k$

for si $\frac{dI_s/dT}{I_s} \cong 0.16$

$$\frac{dV_D}{dT} = \frac{700}{300} - 25 \times 0.16 = \frac{7}{3} - 4 \text{ mV/k}$$

measured $\frac{dV_D}{dT}$ @ $I_D = 1mA$ is found

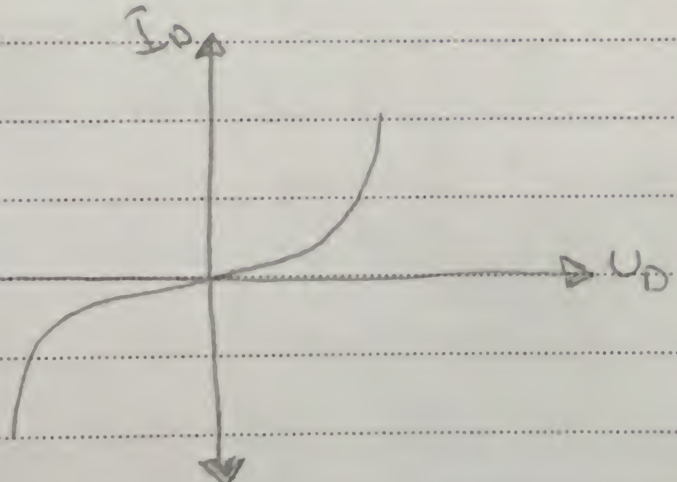
to be $\sim -2mV/K^{\circ}$



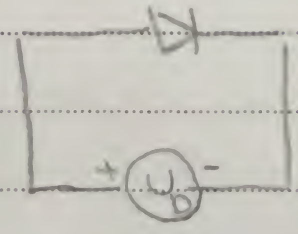
— Breakdown diode :-

Break down is electrical (Not mechanic

(i.e No damadge)



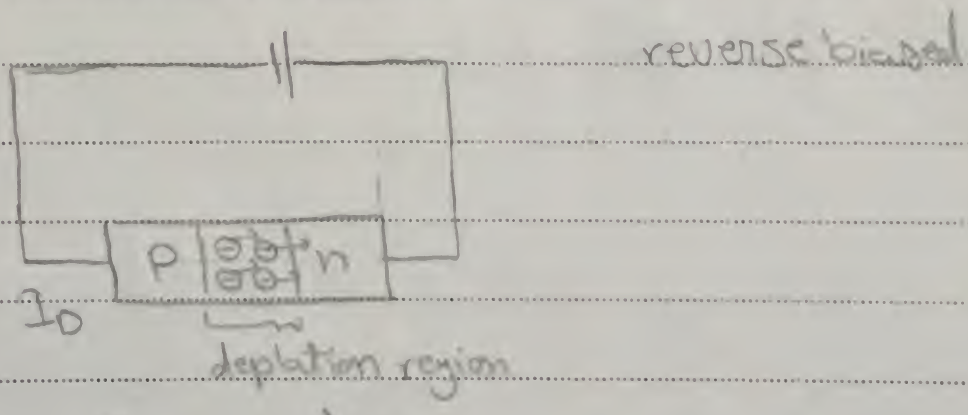
forward biased



- Break down mechanism (Two) :-

1- Zener break down :-

In a heavily doped pn junction The Then deplation region when the reverse biased is high enough to develop a very strong field across the junction whic exciter electrons from the valance band whithin the Junction to the conduction band

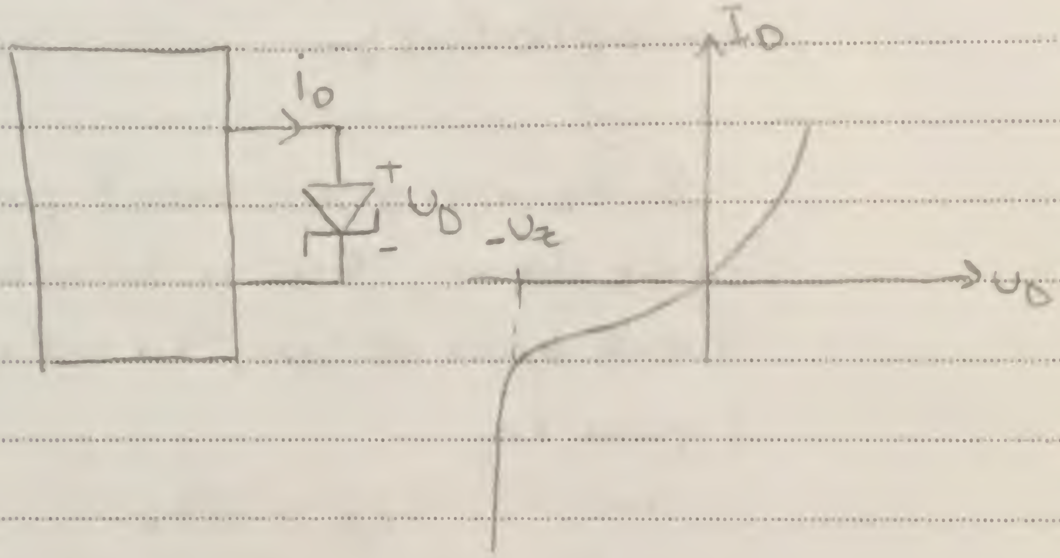


I_D negative

Zener break down occers at $\varepsilon_{max} \geq 10^6 \, V/cm$ and doping in the range of $10^{18}/cm^3$

Zener diode symbale 

break down voltage V_Z => breakdown occers if $V_D \leq -V_Z$



(2) Avalanche break down :-

when reverse biased is increase in a not heavily doped p-n junction [Thick deplation region] until The field $\mathcal{E}_{max}$ reaches 2×10^5 V/cm Then carriers have safficient energy in colliding with other atoms in the deplation region producing new electron-hole pairs, The secandariy carriers in دوره trut

Produce more carriers leaving The depletion region [doping level ~ 10^{16} / cm^3

* Impeirical formula for avalanche multiplication :- نتيجة الاصطدام

let I_R = reverse current Just before break down, Then in the avalanche break down region, The reverse current given by

$$I_{RA} = M I_R$$

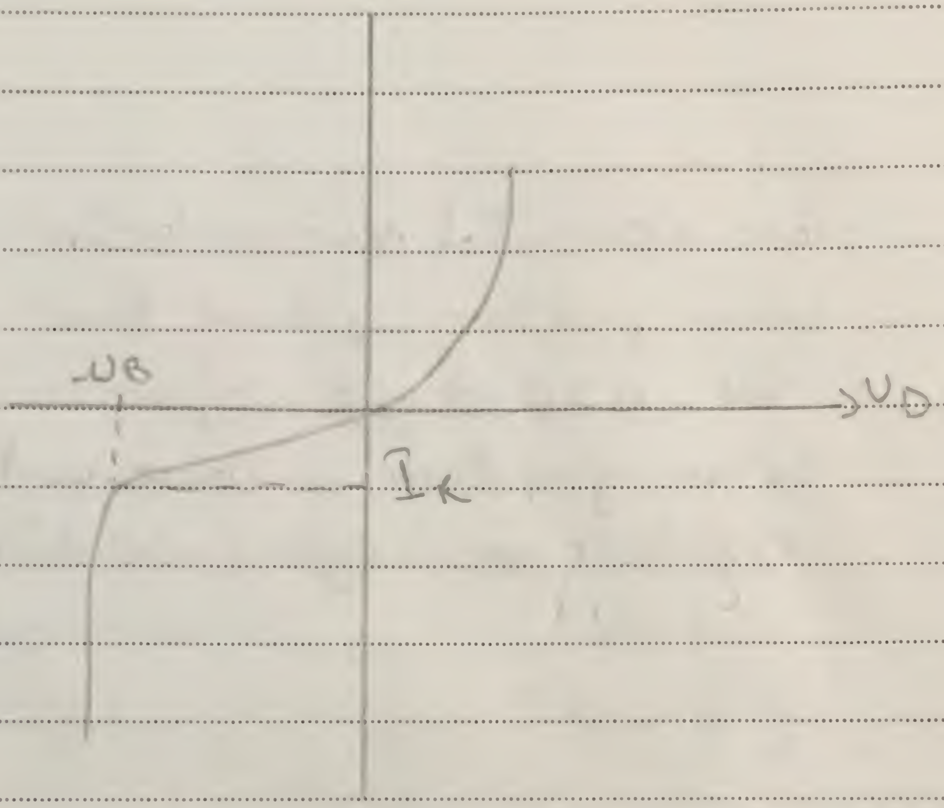
M = multiplication factor

$$M = \frac{1}{\left(1 - \left(\frac{V_R}{V_B}\right)^n\right)}$$

$V_R \rightarrow$ reverse biased

n_i : $3 \rightarrow 6$

Subject: .... / /



تقريبي

Approximate expression for V_B:-
(Break down voltge)
for step p-n junction

$$V_B\,(\text{volts}) \cong 60\left[\frac{E_g}{1.1}\right]^{\frac{3}{2}}\left[\frac{N_I}{10^{16}}\right]^{-\frac{3}{4}}$$

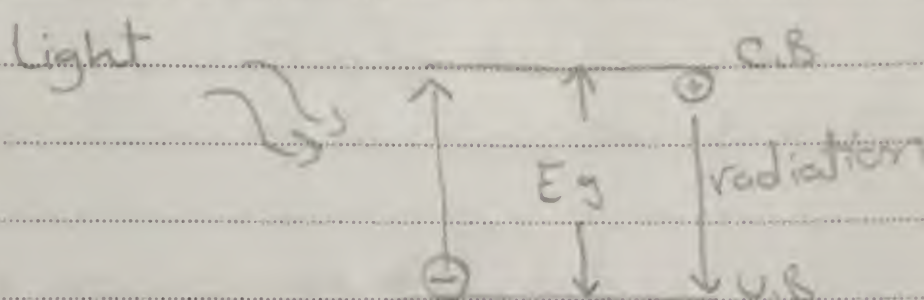
E_g in eV

$V_B > 200$
يستخدم في هذه الحالة

$$N_I = \frac{N_A N_D}{N_A + N_D}$$

for elemental semiconductor

- homo junction → same base material for n&p-type region
- hetro junction → base material p&n type region are different



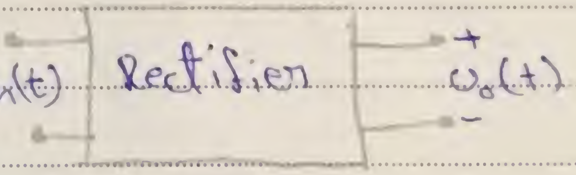
reminder read lecture
with date 29/4/2017
before this →

Subject: / /

2/5/2017

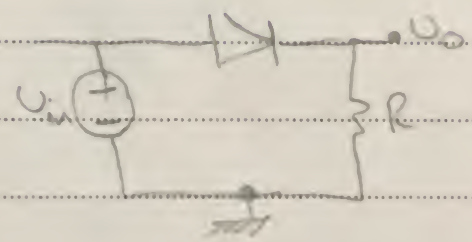
Rectifier cKts :-

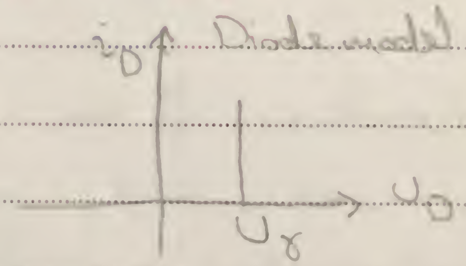
v_{in} can be +ve & -ve when as v_o is either +ve only or -ve only



$\Rightarrow v_o(t) = \pm \alpha |v_{in}(t)|$

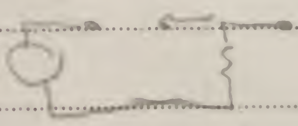
- half wave Rectifier (Hwf) :-

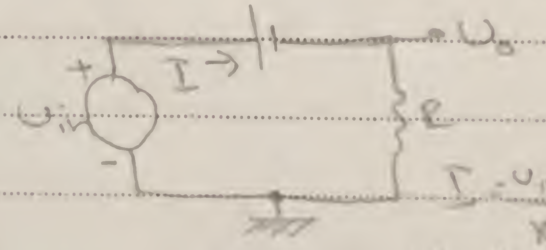




- Diode off if $v_{in} < v_\gamma$

  $v_o(t) = 0$



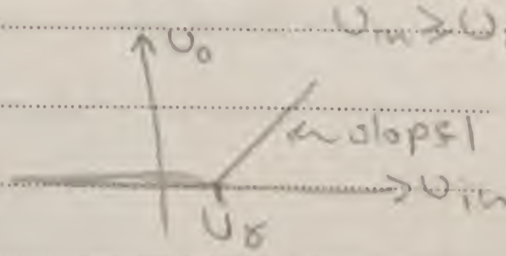


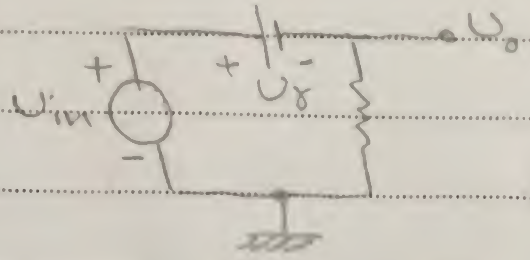
$I = \frac{v_{in} - v_\gamma}{R}$

$v_{in} \geq v_\gamma$

- Diode is on if $v_{in} \geq v_\gamma$

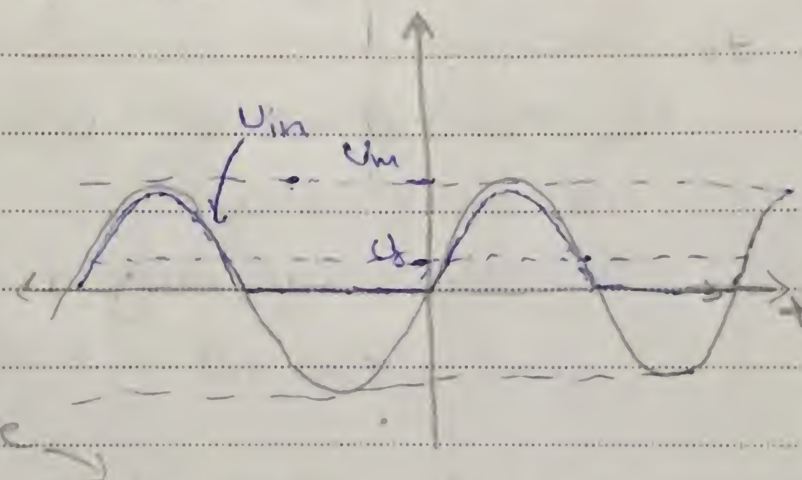
  $v_o = v_{in} - v_\gamma$





$$v_{out}(t) = \begin{cases} 0 & \text{if } v_{in} < V_\gamma \\ v_{in} - V_\gamma & \text{if } v_{in} \geq V_\gamma \end{cases}$$

$v_{in} = V_m \sin \omega t$



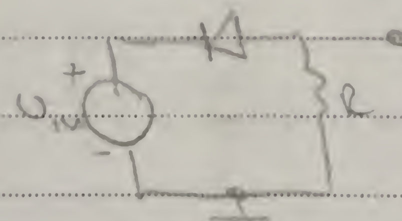
on the case

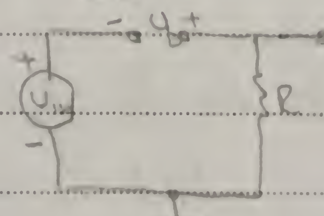
Diode is off for $v_D < V_\gamma$

$\Rightarrow -v_{in} < V_\gamma$

$\Rightarrow v_{in} > -V_\gamma$

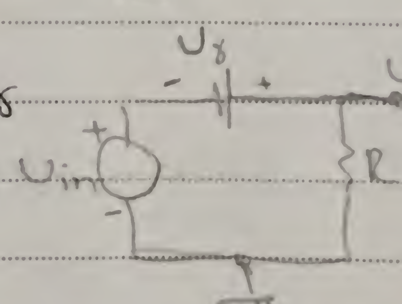
$v_o = 0$

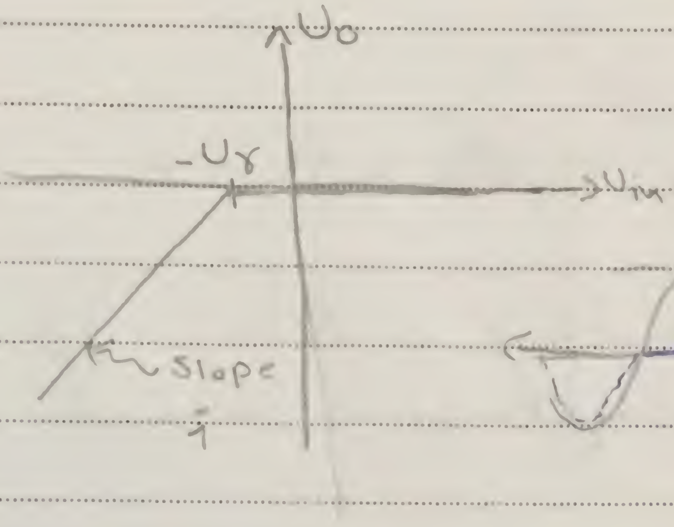


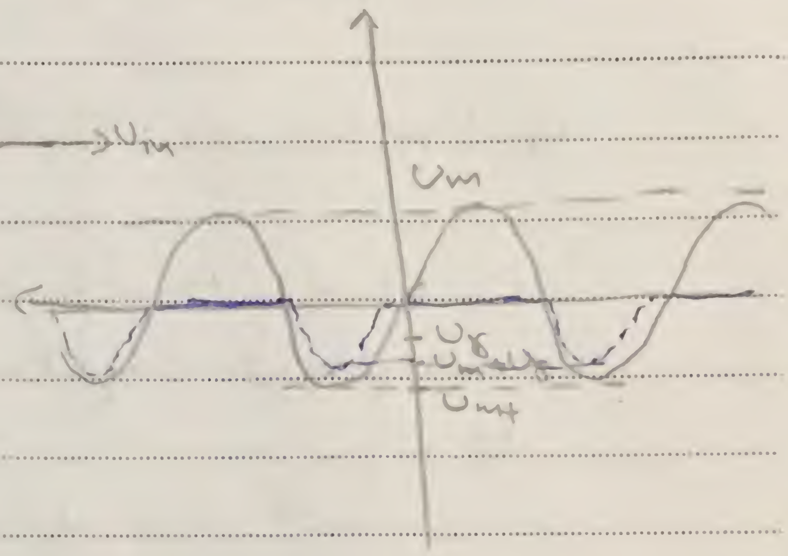


- Diode is on for $v_{in} \leq -V_\gamma$

$v_o = v_{in} + V_\gamma$

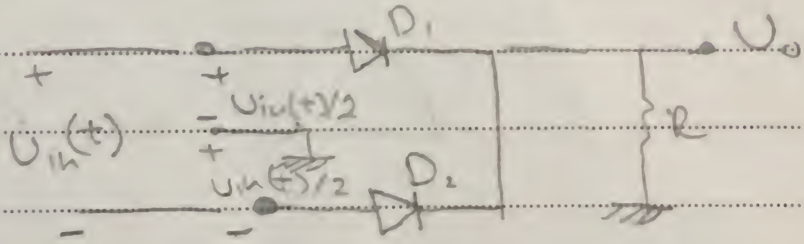






- Full wave Rectifier (FWR) :-

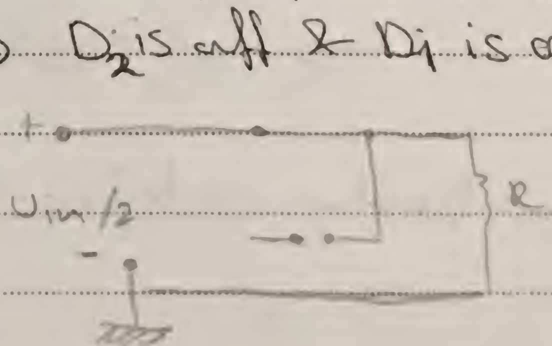
v_{in} — FWR — $v_o(t) = \pm \alpha |v_{in}(t)|$



assume diodes are ideal ($R_f = 0$, $V_\gamma = 0$, $R_r = 0$)

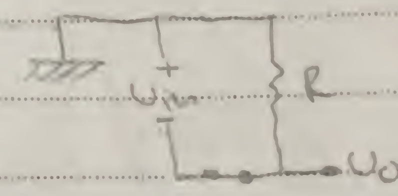
if $v_{in} \geq 0 \Rightarrow D_2$ is off & D_1 is on

$v_o = v_{in}/2$



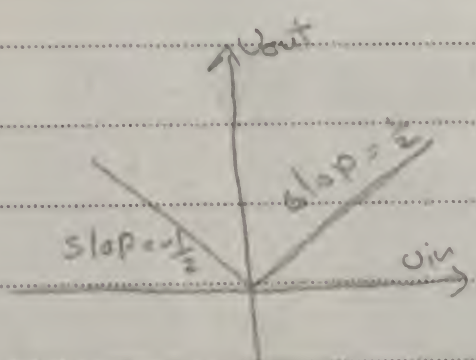
if $v_{in} < 0 \Rightarrow D_1$ off & D_2 on

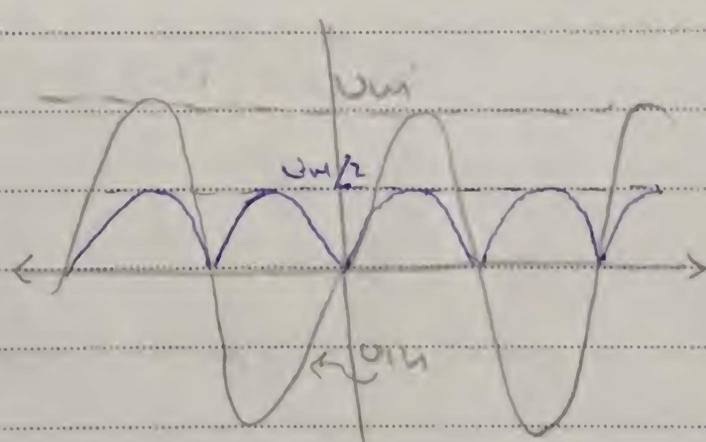
$v_o = -v_{in}/2$



$$v_o = \begin{cases} v_{in}/2 & \text{if } v_{in} \geq 0 \\ -v_{in}/2 & \text{if } v_{in} < 0 \end{cases}$$

$$\Rightarrow v_o = \frac{1}{2}|v_{in}|$$

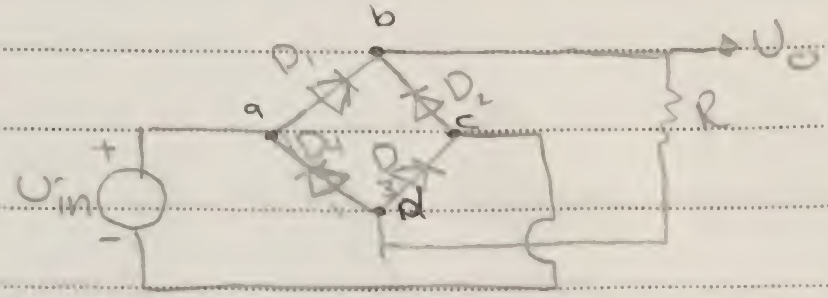




$v_{in} = V_m \sin \omega t$

$$\Rightarrow v_o = \frac{V_m}{2}|\sin \omega t|$$

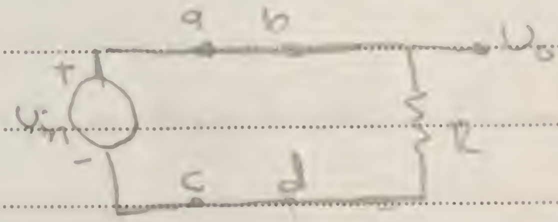
- Bridge Rectefire (FWR) :-



Assume diodes are ideal

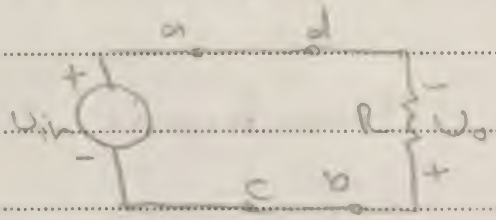
- for $v_{in} \geq 0 \Rightarrow D_1$ & D_3 on, D_2 & D_4 off

$v_o = v_{in}$



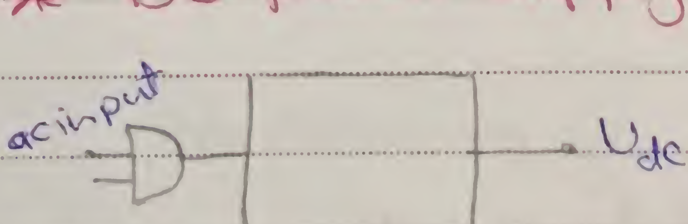
- for $v_{in} < 0 \Rightarrow D_1$ & D_3 off, D_2 & D_4 on

$v_o = -v_{in}$



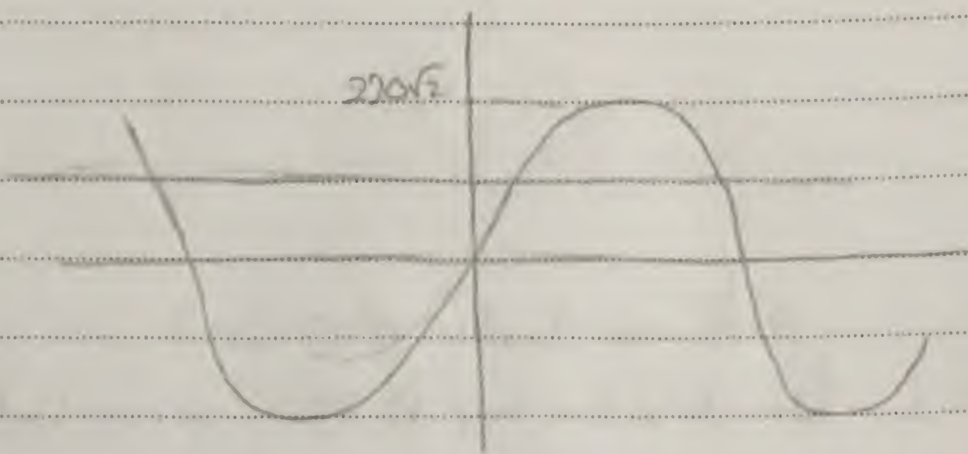
$\therefore v_o = |v_{in}|$

* DC power supply :- all Digital ckts

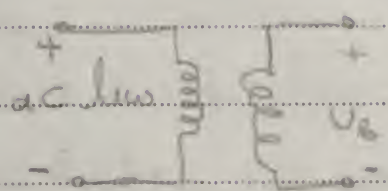


$220\sqrt{2} \sin wt$

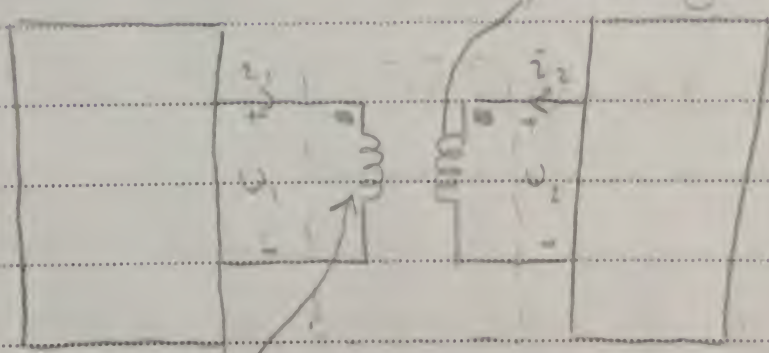
$w = 100\pi$ rad/s



- Black diagram of Dc power supply



Transformer (تخفيض جهد)



N_1 = # of the primary

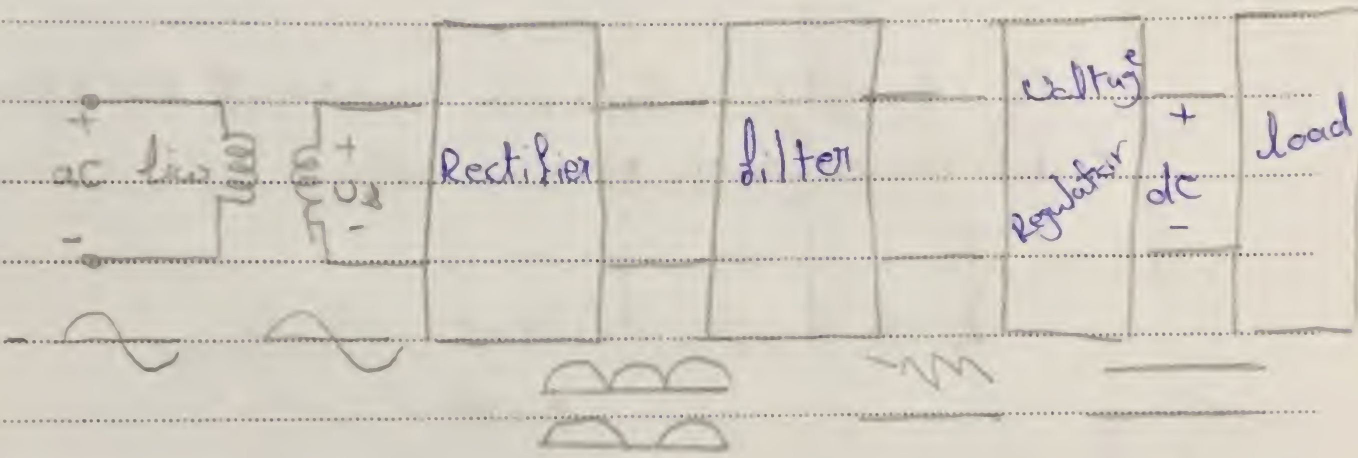
N_2 = # of the secondary ثانوي

Subject: .... / /

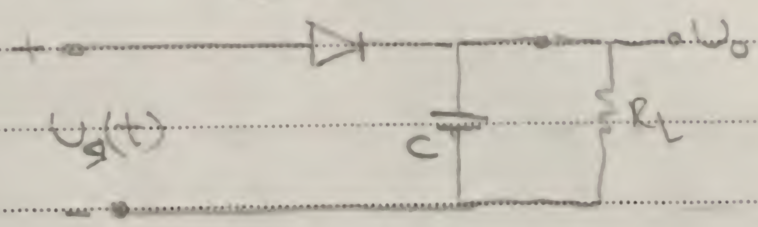
$$P_1 = P_2 \Rightarrow v_1 i_1 = v_2 i_2$$

$$\frac{v_2}{v_1} = \frac{i_1}{i_2}$$

Back to block diagram

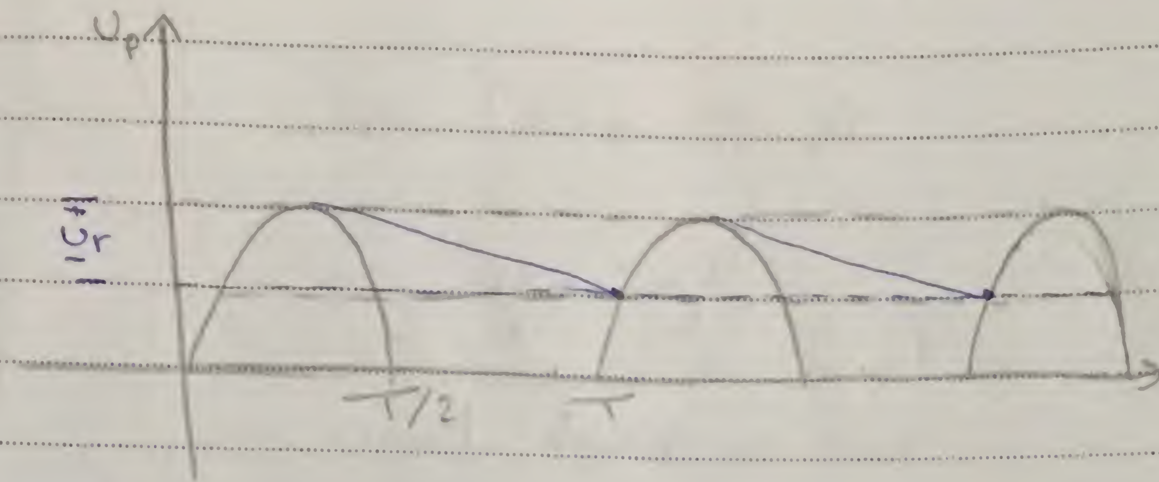


(capacitor) يسمى (filter)



$$V_s(t) = V_p \sin \omega t \quad , \quad \omega = 2\pi f = \frac{2\pi}{T}$$

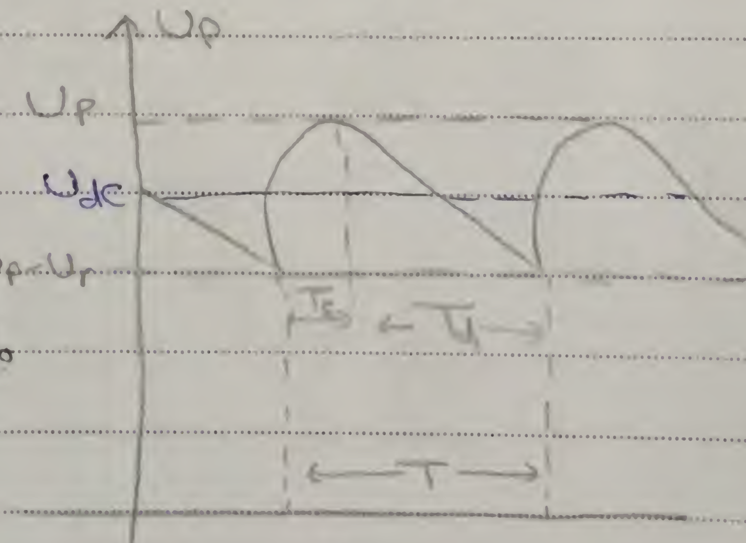
$$f = 50 \Rightarrow T = \frac{1}{50} = 20ms$$



C charges with time constant $R_f C$ (very small)

C discharges with time constant $R_L C$ (very large)

$V_r \triangleq$ Ripple voltage



V_{dc} = average of V_o

$V_{dc} = V_p - \frac{V_r}{2}$

2/5/2014

Tutorial

Quistion (eight) :-

$$n_i(T_1) = (N_c N_v)^{\frac{3}{2}} e^{\frac{-E_g}{2K_BT}}$$

$$\frac{n_i(T_1)}{n_i(T_0)} = \left(\frac{T_1}{T_0}\right)^{\frac{3}{2}} e^{\frac{-E_g}{2K_B}\left(\frac{1}{T_1} - \frac{1}{T_0}\right)}$$

constant constant

$$N_c = n_c T^{\frac{3}{2}} \ , \ N_v = n_v T^{\frac{3}{2}}$$

$$i_D = I_S(e^{v_D/v_T} - 1)$$

$$i_D = -I_S = -15PA \quad @ \ 25C^\circ$$

$$n_i(75) = n_i(25) \frac{(75+273)}{(25+273)} e^{\frac{-E_g}{2K_B}\left(\frac{1}{348} - \frac{1}{298}\right)}$$

Quistion (Three) :-

$$U_D = 0 \qquad C_j = 19.9\,pF$$

$$C_j = \frac{C_{jo}}{\sqrt{\phi_o}} \Rightarrow \phi_o (19.9\,pF)^2 = (C_{jo})^2$$

if junction is step

(a) $U_D = -0.5 \qquad C_j = \dfrac{C_{jo}}{\sqrt{1+0.5/\phi_o}} = 17.3$

$$\sqrt{1 + \frac{0.5}{\phi_o}} = \frac{C_{jo}}{17.3} = \frac{19.9}{17.3}$$

$$\left(1 + \frac{0.5}{\phi_o}\right) = \left(\frac{19.9}{17.3}\right)^2$$

$$\frac{0.5}{\phi_o} = \left(\frac{19.9}{17.3}\right)^2 - 1$$

$$\phi_o = \frac{0.5}{\left(\frac{19.9}{17.3}\right)^2 - 1}$$

$$v_D = -1$$

$$C_j = \frac{C_{j0}}{\sqrt{1 - V_D/\phi_0}}$$

ونضبن ونشوف اذا كانت النتائج قريبه اذا تقترب
واذا طلعت وحده منهم بعيده اذا ليست step
step و linearly (معطاهاش)

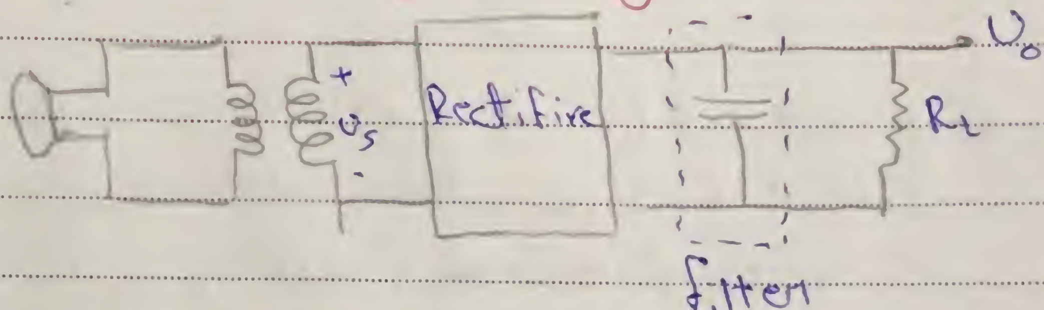
Ps #4 P#4

Assume $n_i = 1.5 \times 10^{10} / cm^3$
$\mu_n = 1600\ cm^2/V.s$ $\mu_p = 500\ cm^2/V.s$
life time of minority carriers in p-reg $100\mu s$
" " " " " n $2\mu s$

Subject: .... / /

6/5/2017

* dc power supply (un regulated):-



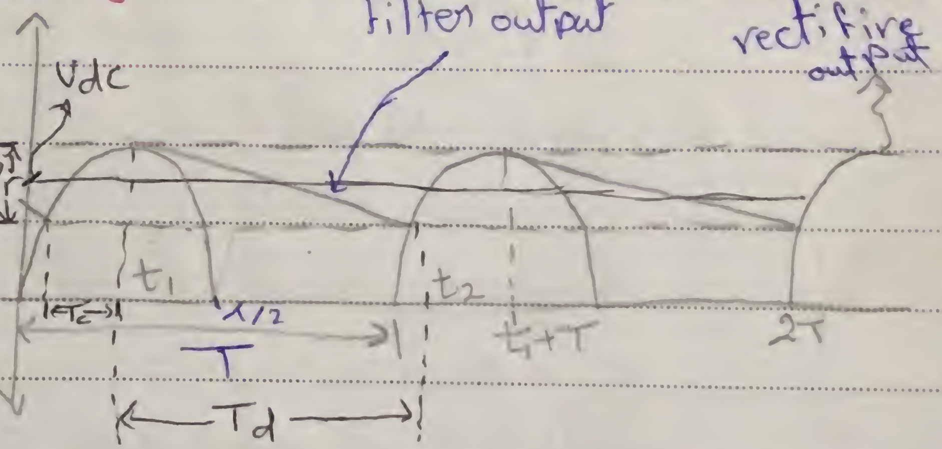
* for HWR :-

Diod ... Ideal

$V_p = V_m$

$V_s = V_m \sin \omega t$

$V_p = V_m - V_r$



V_r = ripple voltage

V_{dc} = average output voltage $= V_p - V_r/2$

- During T_c, The capacitor charges (Diod is on) with a very small time constant $\tau_c = R_f C$ ($R_f << R_L$)

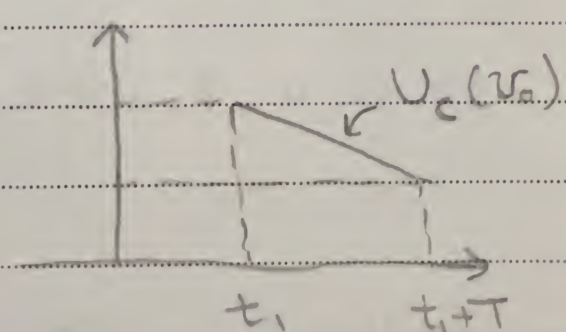
$\Rightarrow$ T_c is very small (compared to T)

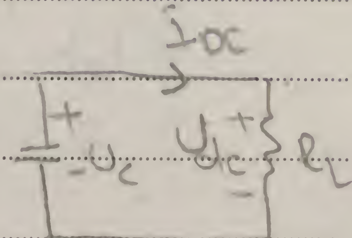
- During T_d The capacitor discharges
Diodis off with a very long time
constant $\tau_d = R_L C$

$\Rightarrow$ T_d is very long

- Assumptions :-
$T_d \cong T$, neglect T_c
$t_2 \cong t_1 + T$

- Estimate V_r :-
C discharges @ constant current I_{DC}





let dQ = amount of charge Lost by capacitor
during T_d (T)

$$dQ = Q(t_1) - Q(t_1 + T)$$
$$= C V_c(t_1) - C V_c(t_1 + T)$$
$$= C V_p - C[V_p - V_r]$$
$$= C(V_p - (V_p - V_r)) = C V_r$$

also $dQ = I_{DC} T_d = I_{DC} T = \frac{V_{DC} T}{R_L}$

$$C V_r = \frac{V_{dc}}{R_L} \Rightarrow V_r = \frac{V_{dc} T}{R_L C} = \frac{V_{dc}}{f R_L C} \quad \left(F = \frac{1}{T}\right)$$

$$V_r = \frac{V_p - V_r/2}{f R_L C} \Rightarrow V_r\left[1 + \frac{1}{2 f R_L C}\right]$$

$$= \frac{V_p}{f R_L C} \Rightarrow V_r = \frac{2 V_p}{1 + 2 f R C} \cong \frac{V_p}{f R_L C}$$

Example :-

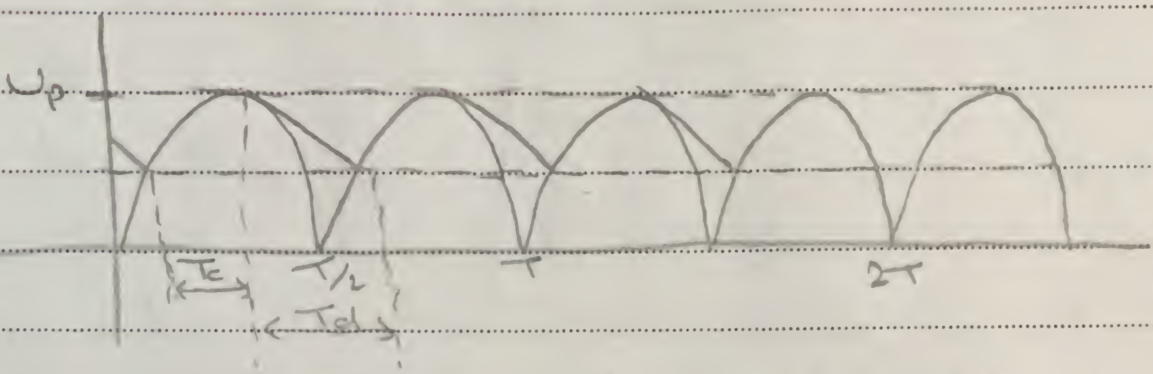
let $V_p = 5V$, $C = 100\mu$, $R_L = 10k\Omega$

$f = 50$

$$V_r = \frac{2 \times 5}{1 + 2 \times 50 \times 10^{4} \times 10^{-4}} = \frac{10}{101} \cong 0.1$$

Subject:

* for (FWR):- يكون v_r أقل من الـ $v_{r_{HWR}}$



Neglect $T_c \Rightarrow T_d \cong T/2$

using the same argument

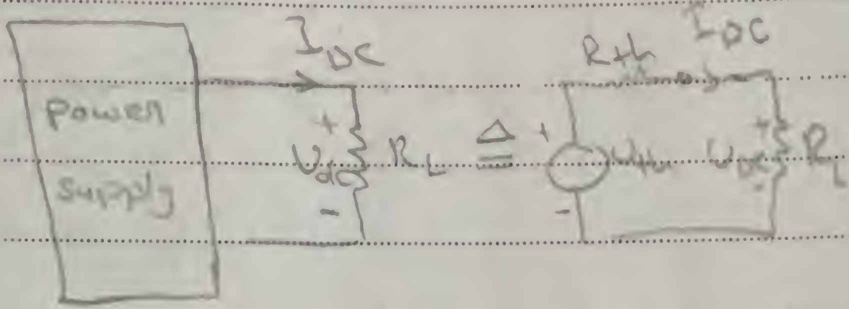
$$V_r = \frac{V_{dc} T_d}{R_L C} = \frac{V_{dc} T}{2R_L C} = \frac{V_{dc}}{2fR_L C}$$

$$\Rightarrow V_r = \frac{V_p - V_r/2}{2fR_L C}$$

$$\Rightarrow V_r\left[1 + \frac{1}{4fR_L C}\right] = \frac{V_p}{2fR_L C}$$

$$V_r = \frac{2V_p}{1+4fR_L C} \cong V_p/2fR_L C$$

- Thevenin's equivalent circuit of dc power supply :-

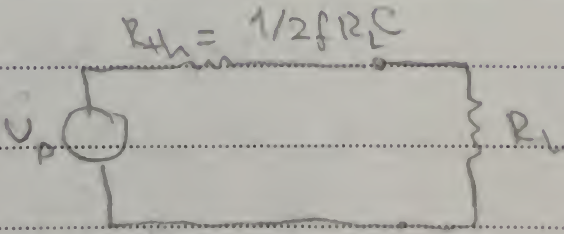


$$V_{dc} = V_p - V_r/2$$

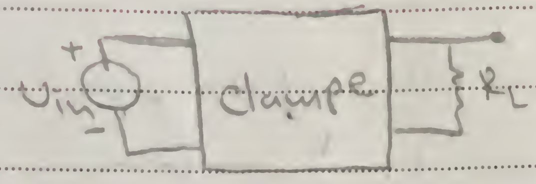
- for HWR :-

$$V_{dc} = V_p - \frac{V_p}{2fR_LC}$$

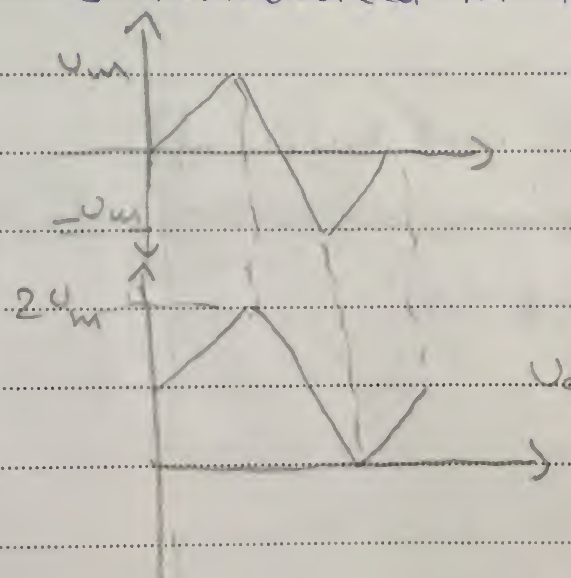
$$V_p = V_{dc} + I_{dc} R_{th}$$



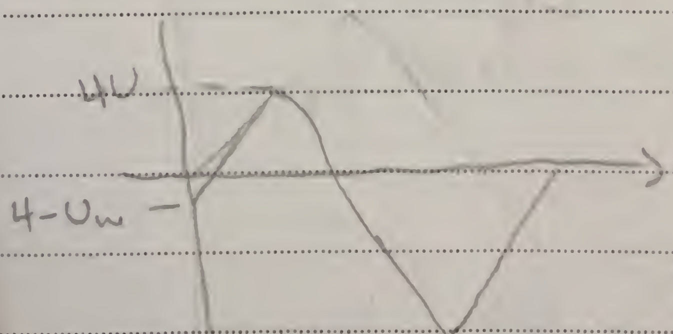
* Clamping circuits :-



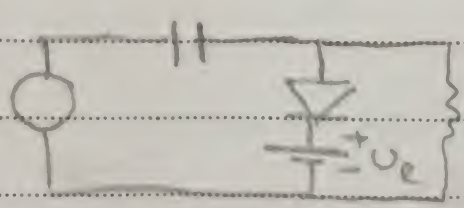
shape of The output is the same as the shape of input but clamped at maximum value in other words a dc off set is introduced in to the output



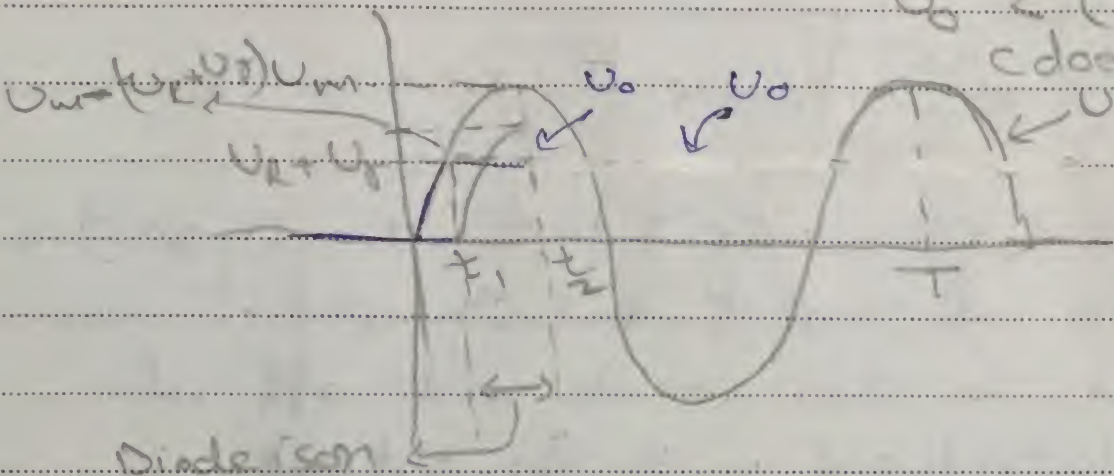
$V_o = V_{in} + V_m$



$V_o = (4 - V_m) + V_{in}$

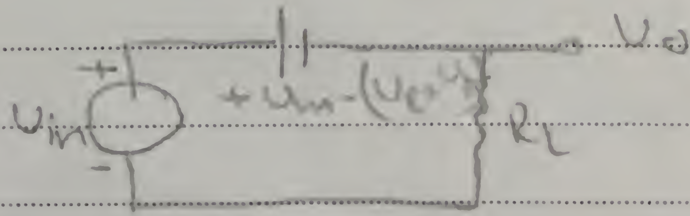


R_L is very large
Diode is off if $T <<< R_C$
$v_o < (v_R + v_\gamma)$
C doesn't charge



After t_2 diode will turn off
$\Rightarrow$ capacitor becomes as battery charged to $v_m-(v_R+v_\gamma)$

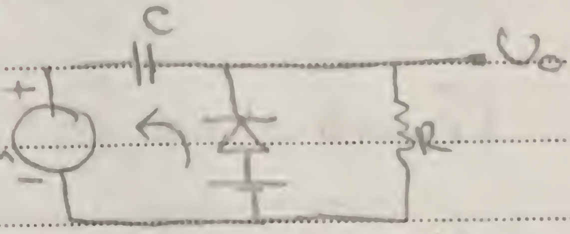
$$v_o = v_m - \delta - [v_m-(v_R+v_\gamma)]$$
$$= (v_R+v_\gamma) - \delta \rightarrow \text{delta}$$



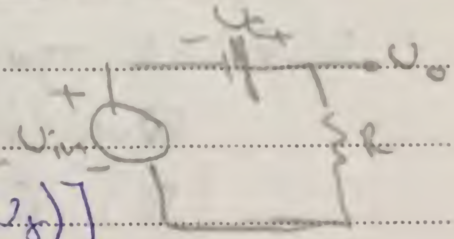
$$v_o = v_m - [v_m-(v_R+v_\gamma)]$$

Condition for clamping
$$T <<< RC$$
$$v_m > (v_R+v_\gamma)$$

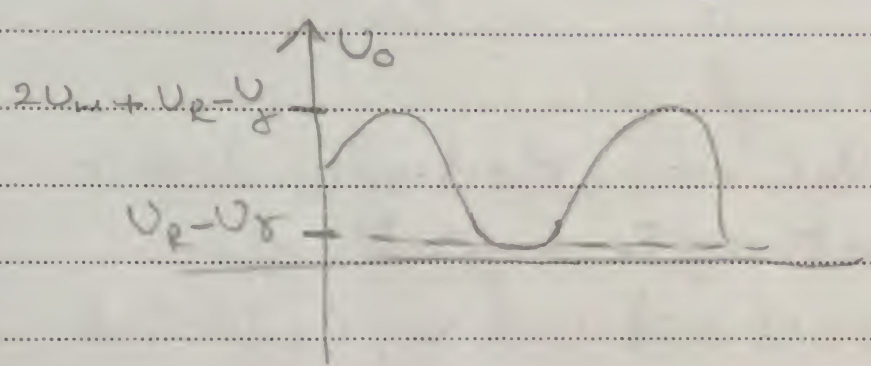
— another clamper :-

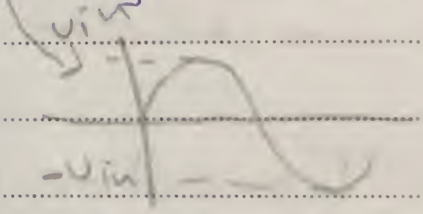


Capacitor charges to $(V_R - V_\gamma) - (-V_m)$



$$V_C = V_m + (V_R - V_\gamma)$$
$$V_o = v_{in} + [V_m + (V_R - V_\gamma)]$$





Condition for clamping

$$T <<< RC$$
$$(V_R - V_\gamma) > -V_m$$

9/5/2017

Transistor (Transfer resistor):-

مقاوم التحويل

BiBlar Junction Transistor (BJT) — ثنائي القطبية

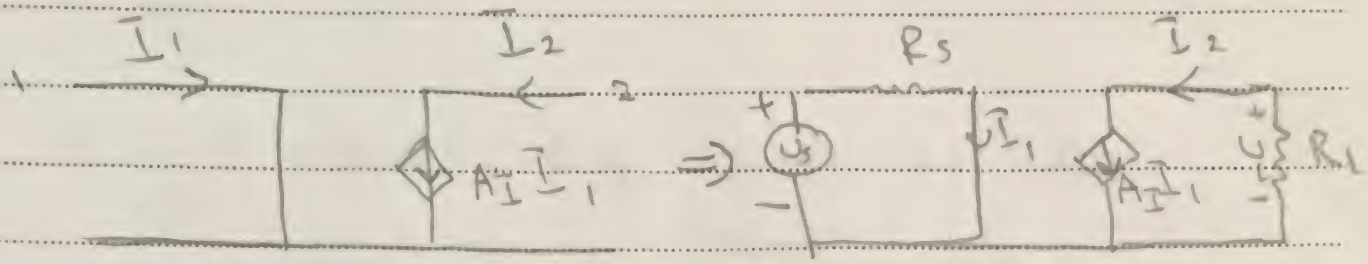
Field Effect Transistors (FETs) — التأثير المجالي

Transistor is the main electronic device for complification & switching

- Amplification is achived by controlled source
- Transistor exhibit controlled source characteristics

Controlled sources:-

- Ideal current controlled source:-



Ideal CCCS

$$v_L = -R_L I_2 = -R_L A_I I_1$$

$$I_1 = \frac{v_S}{R_S}$$

$$v_L = -A_I \frac{R_L}{R_S} v_S$$

$\Rightarrow$ The ~~gai~~ current gain $= \frac{I_2}{I_1} = A_I$

The voltage gain $\triangleq A_v = \frac{v_L}{v_S} = -A_I \frac{R_L}{R_S}$

if $v_S = 20 \sin \omega t$ (mV), $A_I = 100$, $R_L = 4\Omega$, $R_S = 1$

$\Rightarrow A_v = -100 \times \frac{4}{1} = -400$

$$v_L = A_v v_S = -8000 \sin \omega t \text{ mV}$$
$$= -8 \sin \omega t \text{ V}$$

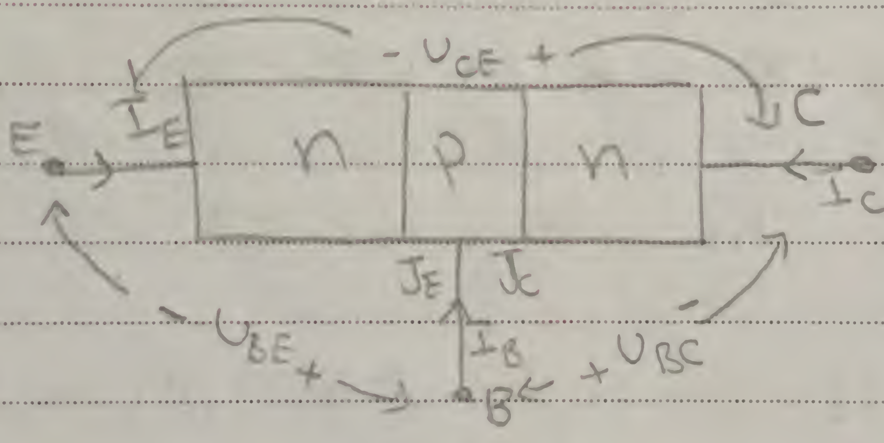
$\Rightarrow$ The power gain: $A_p = \frac{P_L}{P_S}$

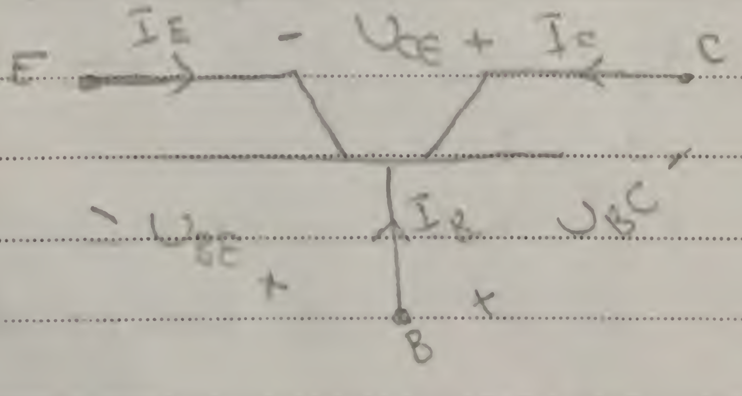
$P_L = I_2^2 R_L$, $P_S = R_S I_1^2$

$$A_p = \frac{R_L}{R_S}\frac{I_2^2}{I_1^2} = \frac{R_L}{R_S}\left(\frac{I_1 A_I}{I_1^2}\right)^2 = A_I^2 \frac{R_L}{R_S}$$

BJTs (Two types):-

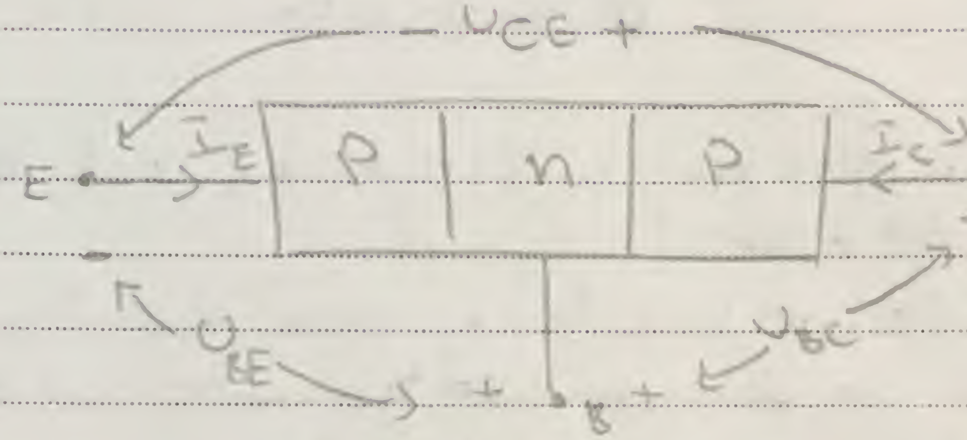
(1)

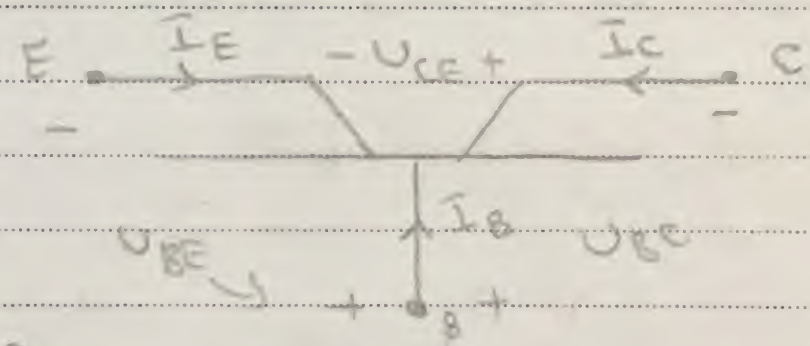




- E ≙ Emitter (Emitts carriers in to Base when J_E forward Biased).
- B ≙ Base Region (very narrow compared to Emitter & Collector regions)
- C ≙ collector (collects carriers from Base).

(2)

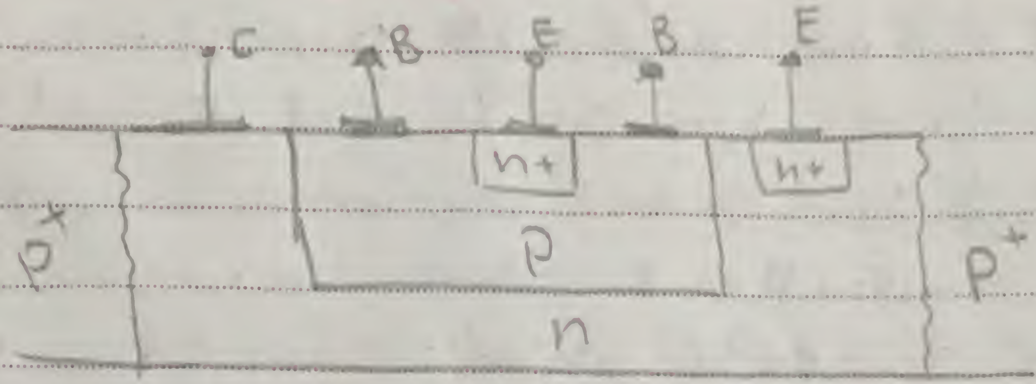




PNP second Type

Subject: .... / /

structure of BJT

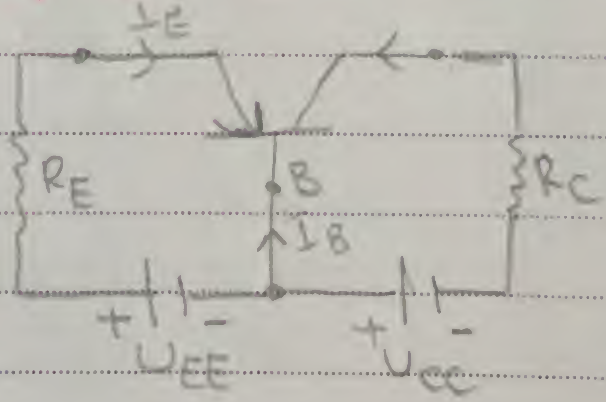


P substrate

- Emitter has higher doping level than collector
- collector has large area than Emitter to be able to collector more carriers from base and handle more power

physical behavior of BJT :-

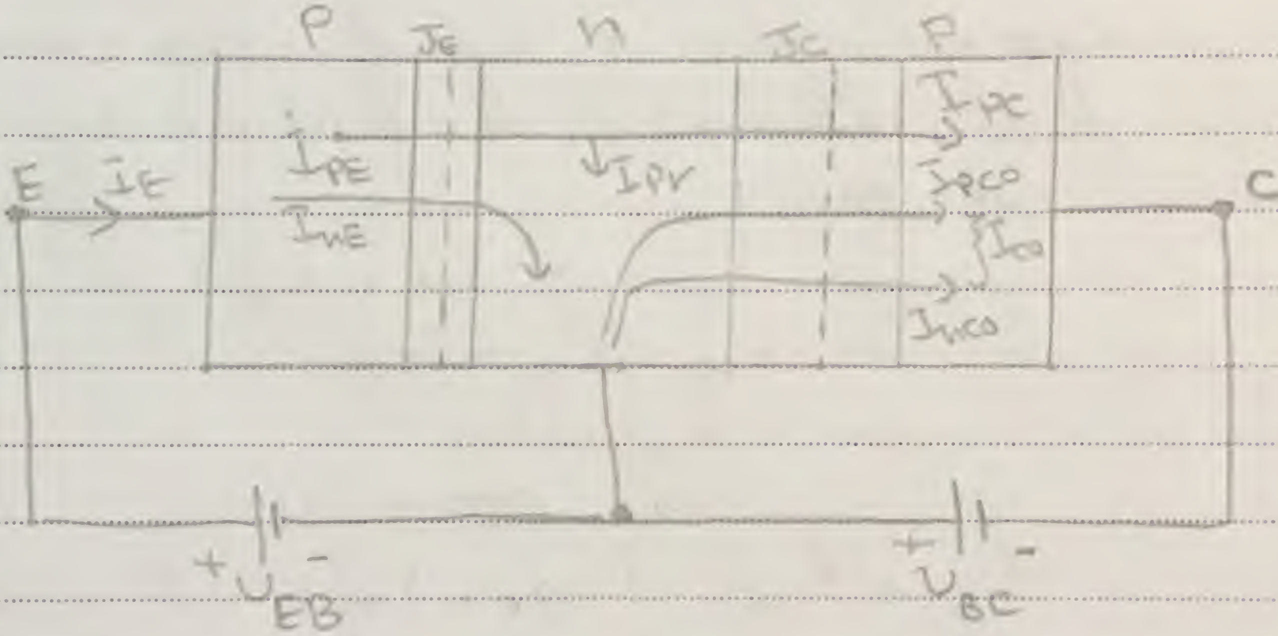
consider a pnp with JE forward Biased & Jc reverse biased



Remember :-

- V_{EB} (V_{CB}) appear directly across the junction J_E & J_C respectively
- no drift current in neutral region

⇒ All current component in a BJT are diffusion currents.



- if E is open ⇒ revers saturation current I_{co} flow cross JC

$I_{co} = I_{pco} + I_{nco}$

dues to electron from collector to Base

↳ " " holes

$\hat{I}_E = \hat{I}_{pE} + \hat{I}_{nE}$ → Electron injected into E from B

$\hat{I}_{pE}$ → holes emitted into B from E

- $\hat{I}_{nE} \ll \hat{I}_{pE}$ (becomes base is lightly doped compared to Emmitted)
- some of holes injected into base from Emmitter recombine with electrons in the Base giving rize to recombination current $\hat{I}_{pr}$, but most of the holes, reaches the collector

اعادة التركيب

تصل

$$\hat{I}_C = -(\hat{I}_{pC} + \hat{I}_{Co})$$

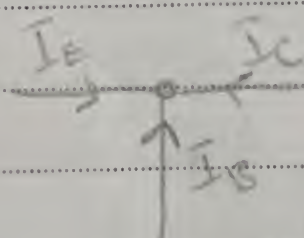
$$\hat{I}_{pC} = \hat{I}_{pE} - \hat{I}_{pr}$$

$$\hat{I}_{pC} \gg \hat{I}_{Co}$$

$$\ggg \hat{I}_{Co}$$

$\frac{\hat{I}_C}{\hat{I}_E}$ تيار الجمع / تيار الدفع

$$\hat{I}_B = \hat{I}_{Co} - (\hat{I}_{pr} + \hat{I}_{nE})$$



$$\hat{I}_E + \hat{I}_C + \hat{I}_B = 0$$

$$V_{EB} + V_{BC} + V_{CE} = 0$$ around the loop

عامل انسياب الالكترونات $\hat{I}_E$

Subject: .... / /

Common Base current gain (α) :-

$$\alpha = \frac{I_{pc}}{I_E} = \frac{I_c - I_o}{I_E}$$

for high gain (α) should be close to unity.

$$\alpha = \gamma\, \alpha_T\, M$$

$M \rightarrow$ collector multiplication factor

$\alpha_T \rightarrow$ Base Transport factor

$\gamma \rightarrow$ Emitter efficiency

$$\gamma = \frac{I_{pE}}{I_E} = \frac{I_{pE}}{I_{pE} + I_{nE}} = \frac{1}{1 + \frac{I_{nE}}{I_{pE}}}$$

$$\alpha_T = \frac{I_{pc}}{I_{pE}} , \quad M = \frac{(I_c - I_{co})}{I_{pc}}$$

$$\Rightarrow \alpha = \gamma\, \alpha_T\, M = \frac{(I_c - I_{co})}{I_E}$$

Condition fo(α) to be close to unity:-

1. Need (γ) close to unity

   $\Rightarrow \frac{I_{nE}}{I_{pE}}$ (very small) $\longrightarrow 0$

   $\Rightarrow$ E is heavely doped compared to B

2. α_T close to unity

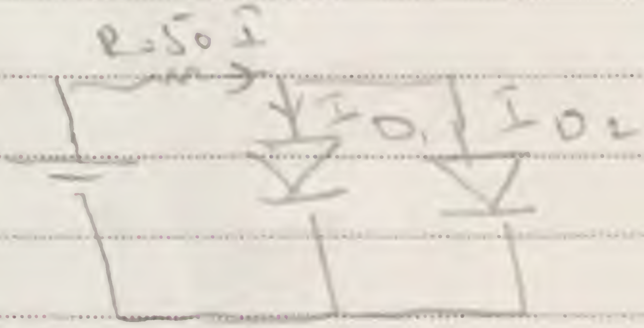
   $\Rightarrow$ reduce I_{pr} $\Rightarrow$ reduce base width

   $\Rightarrow$ make collector area large

Subject: .... / /

Tutorial

Q6)



$v_{D1} = v_{D2}$

$I_{s1} = I_{s2} = I_s (e^{v_D/v_T} - 1)$

$I = 2I_D = \frac{v - v_D}{R} \rightarrow (2)$

$I_{D1} = I_{D2} = I_s (e^{v_D/v_T} - 1) = I_D \rightarrow (1)$

(1) - (2)

Q5 forward $\rightarrow e^{v_D/v_T} \gg 1$

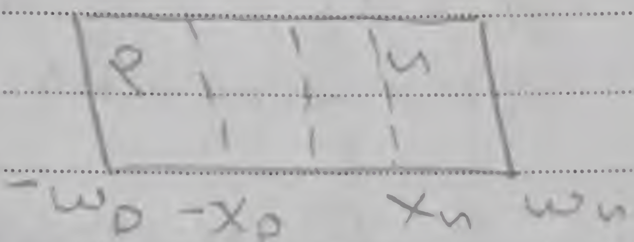
$I_D = I_s e^{v_D/v_T}$

assume v_T

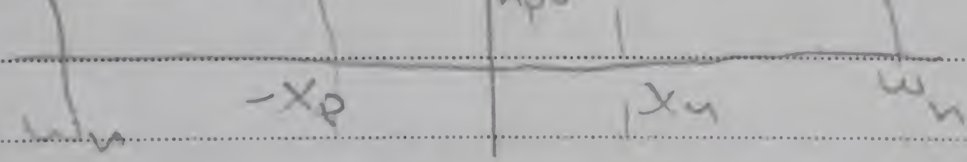
Sum of the problem:-

minority carrier profile of forward biased p-n junction

i) long base Diode



$(w_n - x_n) \gg L_p$, $w_p - x_p \gg L_n$



$$p_n(x) = p_{n0} + p_n'(x)$$
$$= p_{n0} + p_n'(x_n)e^{-(x-x_n)/L_p}$$
$$p_n'(x_n) = p_n(x_n) - p_{n0}$$

$$\Rightarrow p_n'(x) = p_n'(x_n)\, e^{-(x-x_n)/L_p}$$

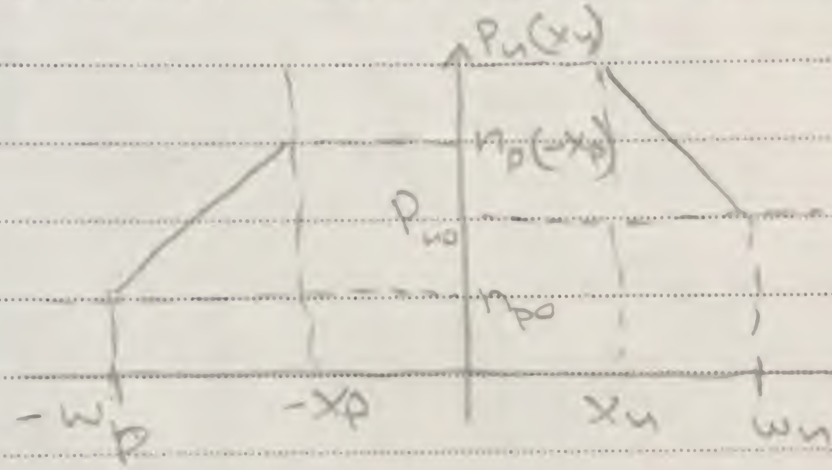
$$p_n(x_n) = p_{n0}\, e^{v_D/v_T}$$

$$n_p(x) = n_{p0} + n_p'(-x_p)\, e^{(x+x_p)/L_n}$$

$$n_p(-x_p) = n_{p0}\, e^{v_D/v_T}$$

$$n_p'(x) = n_p'(-x_p)\, e^{(x+x_p)/L_n}$$

II) short base diode



$$(w_n - x_n) \ll L_p \,, \quad (w_p - x_p) \ll L_n$$

$$p_n(x_n) = p_{n0}\, e^{v_D/v_T}$$

$$n_p(-x_p) = n_{p0}\, e^{v_D/v_T}$$

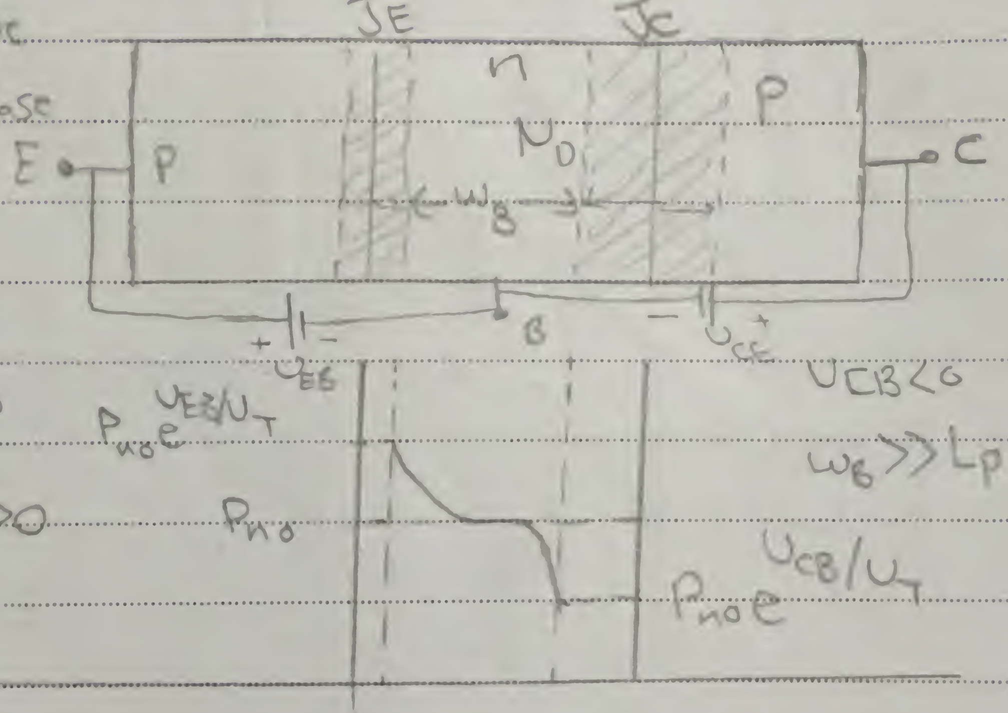
Subject: .... / /

13/5/2017

why Base is narrow ??

Consider a pnp with wide base region with J_E forward Biased & J_C junction reverse biased

w_B : effictive width of Base region



$P_{no} = \frac{n_i^2}{N_D}$

$v_{EB} > 0$

$v_{CB} < 0$

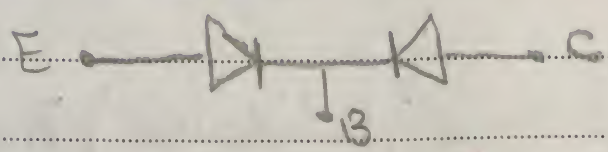
$w_B >> L_p$

Practically all holes injected into the Base region at J_E junction are lost by recombination with electrons

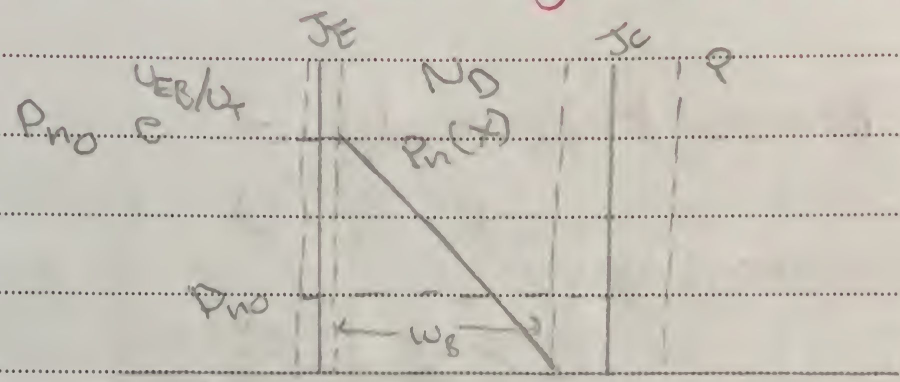
=> None reaches J_C junction

=> No transistor action

⇒ Effectively The two junctions represent Two independent non-interacting back to back diodes



— for narrow Base region ($w_B << L_p$) :-



⇒ most holes injected into Base from emmitter reach the collector

$P_n(x)$ decays exponentially in the Base region.

$$P_n(x) = \underbrace{P_{n0}\, e^{V_{EB}/V_T}}_{P_n(x_{nE})} \; e^{-(x - x_{nE})/L_p}$$

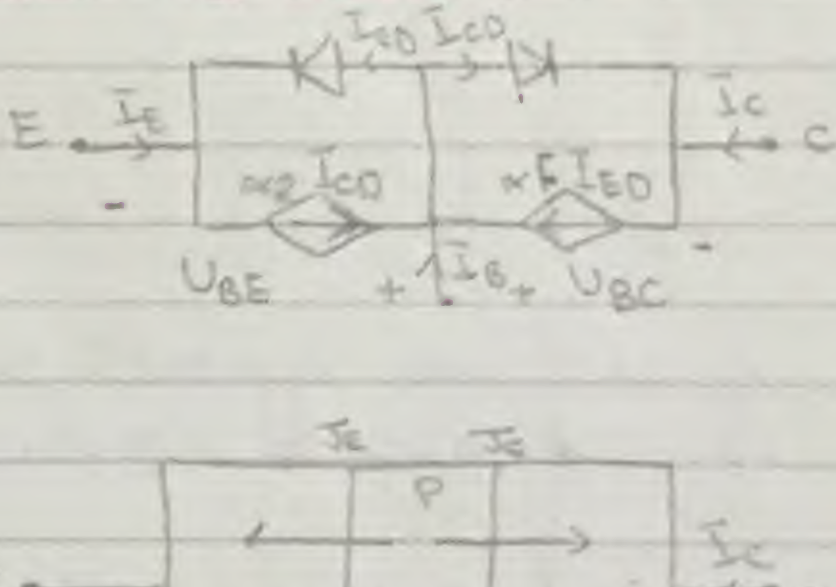
(J_E f.b , J_C R.b)

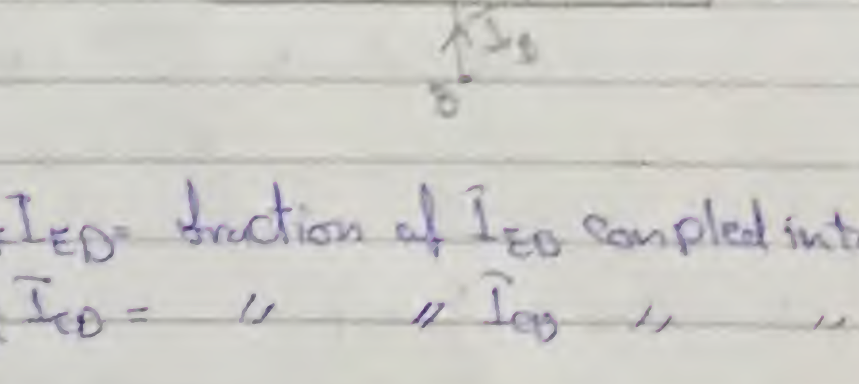
$P_n(x)$ decays linearly in the Base region

$$P_n(x) = P_{no}\, e^{U_{BE}/U_T} - P_{no}\, e^{U_{BE}/U_T}$$

$$= \left(1 - \frac{X - X_{nE}}{W_B}\right) P_{no}\, e^{U_{BE}/U_T}$$

Ebber's Moll model :-





$\alpha_F I_{ED}$ = fraction of I_{ED} coupled into collector
$\alpha_R I_{CD}$ = " " I_{CD} " " Emitter

- $\bar{I}_E = -\bar{I}_{ED} + \alpha_R \bar{I}_{CD} = -\bar{I}_{ES}\left(e^{V_{BE}/V_T} - 1\right) + \alpha_R \bar{I}_{CS}\left(e^{V_{BC}/V_T} - 1\right)$

- $\bar{I}_C = -\bar{I}_{CD} + \alpha_F \bar{I}_{ED} = -\bar{I}_{CS}\left(e^{(V_{BC}/V_T)} - 1\right) + \alpha_F \bar{I}_{ES}\left(e^{V_{BE}/V_T} - 1\right)$

- I_{ES} = reverse saturation current of BE junction
- I_{CS} = " " " BC "

- subscript F in α_F refers to forward transmission from E to C. انتقال
- subscript F in α_R ~~refers~~ forward to reverse transmission from C to E

- $I_{ES}, I_{CS}, \alpha_F, \alpha_R$ are functions in doping densities and transistor علم الهندسة geometry and related by Reciprocity. المعاملة بالمثل

شرط

Condition $\longrightarrow$ $\alpha_R I_{CS} = \alpha_F I_{ES} = \dfrac{qAn_i^2 D_B}{L_B N_B \sinh(W_B/L_B)}$

valid for Both npn & pnp

where :-

A = cross section Area

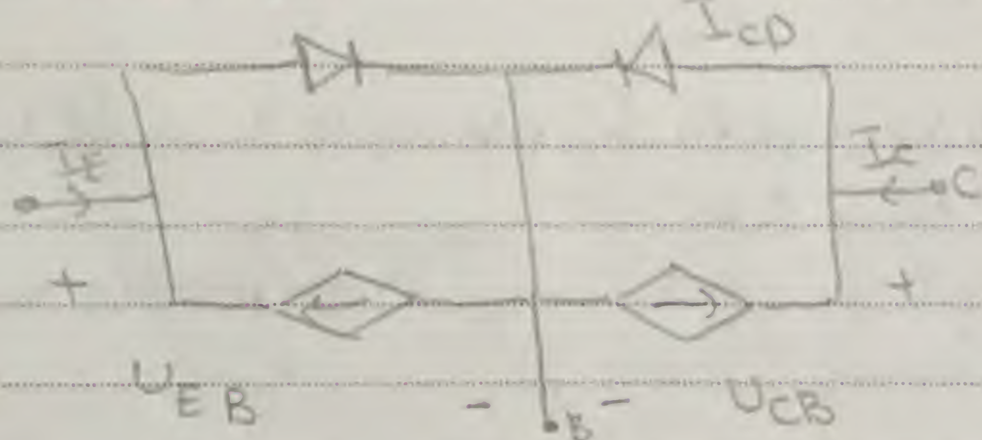
D_B = Diffusion factor of minority carriers in Base region

L_B = Diffusion lenght of minority carriers in Base region

N_B = Doping level in Base region

w_B = Effective width of Base region

PnP :-



$$I_E = I_{ED} - \alpha_R I_{CD} = I_{ES}\left(e^{-U_{BE}/U_T} - 1\right) - \alpha_R I_{CS}\left(e^{-U_{BC}/U_T} - 1\right)$$

$$I_C = I_{CD} - \alpha_F I_{ED} = I_{CS}\left(e^{-U_{BC}/U_T} - 1\right) - \alpha_F I_{ES}\left(e^{-U_{BE}/U_T} - 1\right)$$

Typical values for α_F & α_R :-

$$0.98 \leq \alpha_F \leq 0.998$$

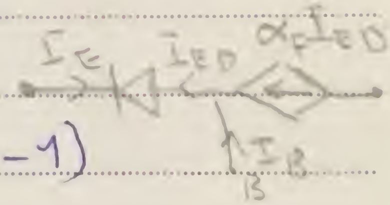
$$0.4 \leq \alpha_R \leq 0.8$$

Large signal current gain :-

consider The npn with J_E forward Biased and J_C reverse biased by short circuiting

$$\left(U_{BE} = U_{\gamma E} \;,\; U_{BC} = 0\right)$$

$$I_{CD} = I_{CS}\left(e^{U_{BC}/U_T} - 1\right) = 0$$



$$I_E = -I_{ED} = -I_{ES}\left(e^{U_{BE}/U_T} - 1\right)$$

$$I_C = \alpha_F I_{ED} = \alpha_F I_{ES}\left(e^{U_{BE}/U_T} - 1\right) = -\alpha_F I_E$$

$$\alpha_F = \left.\frac{-I_C}{I_E}\right|_{U_{BC}=0}$$

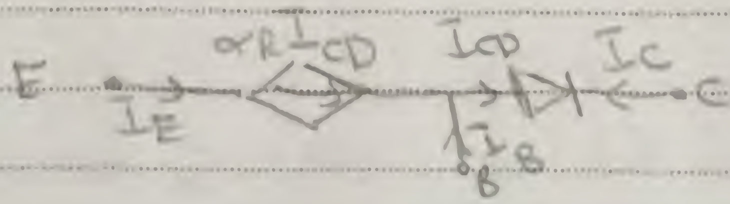
for Both Pnp & npn

$\alpha_F \triangleq$ common base forward short circuit current gain

لو كانت حالتها & [illegible] نستعمل على BC

If J_C Forward Biased & $U_{BE} = 0$ $\left(U_{BC} = U_{\gamma C}\right)$

$$\Rightarrow I_{ED} = 0 \;,\; I_{CD} = I_{CS}\left(e^{U_{BC}/U_T} - 1\right)$$



$$\bar{I}_C = -\bar{I}_{CD} = -\bar{I}_{CS}\left(e^{v_D/v_T} - 1\right)$$

$$\bar{I}_E = \alpha_R \bar{I}_{CD} = -\alpha_R \bar{I}_C$$

for Both pnp & npn

$$\alpha_R = \frac{-I_E}{I_C}\Bigg|_{v_{BE}=0} \triangleq \text{common base reverse short circuit current gain}$$

$$\bar{I}_B = -(\bar{I}_C + \bar{I}_E)$$

for J_E f.b. & $v_{BC}=0$

$$\bar{I}_B = -(-\alpha_F \bar{I}_E + \bar{I}_E) = -(1-\alpha_F)\bar{I}_E$$

Express $\bar{I}_C$ & $\bar{I}_E$ in terms of I_B

$$\bar{I}_E = -\frac{\alpha_F}{1-\alpha_F}\bar{I}_B \triangleq \beta_F \bar{I}_B$$

$$\beta_F = \frac{\alpha_F}{1-\alpha_F}$$

$$1+\beta_F = \frac{1-\alpha_F}{1-\alpha_F} + \frac{\alpha_F}{1-\alpha_F}$$

$$= \frac{1}{1-\alpha_F}$$

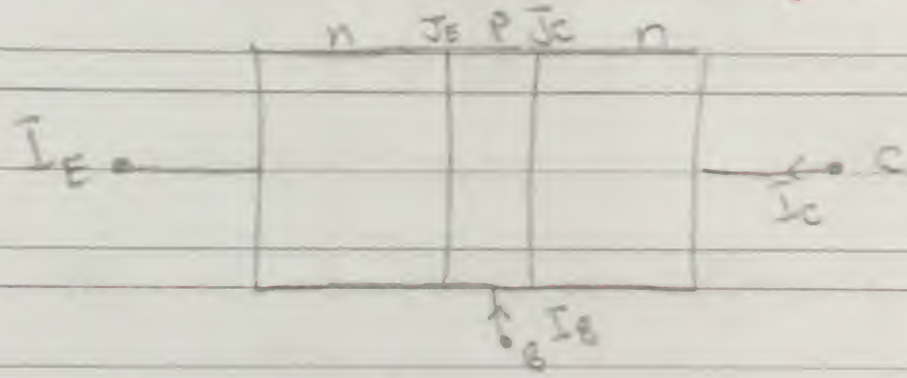
$$\Rightarrow I_E = -(1+\beta_F)\, I_B$$

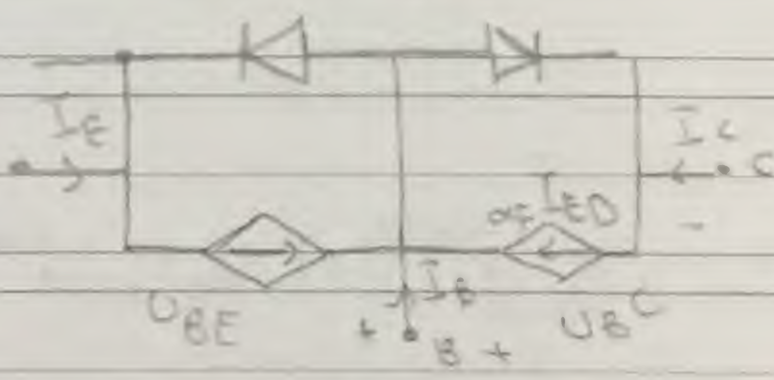
β_F = common Emmiter forward short circuit current gain

Subject:

Subject:

Ebbers Moll model of BJT :-



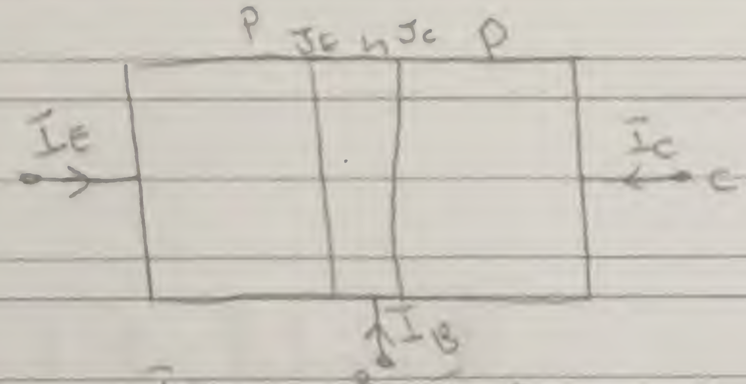


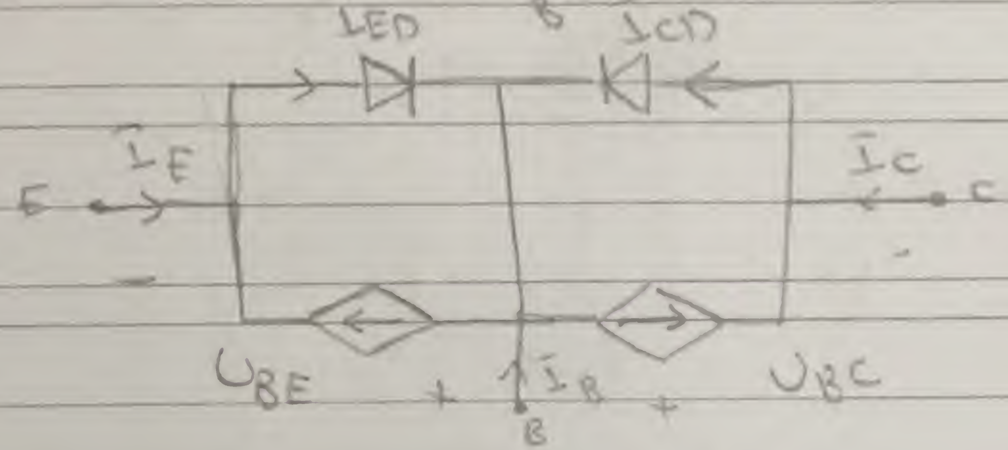
$$\bar{I}_C = \alpha_F \bar{I}_{ED} - \bar{I}_{CD} = \alpha_F \bar{I}_{ES}\left(e^{U_{BE}/U_T} - 1\right) - \bar{I}_{CS}\left(e^{U_{BC}/U_T} - 1\right)$$

$$\bar{I}_E = \alpha_R \bar{I}_{CD} - \bar{I}_{ED} = \alpha_R \bar{I}_{CS}\left(e^{U_{BC}/U_T} - 1\right) - \bar{I}_{ES}\left(e^{U_{BE}/U_T} - 1\right)$$

for (npn)

Subject: ______ / /





for pnp :-

$$I_C = I_{CD} - \alpha_F I_{ED} = I_{CS}\left(e^{-U_{BC}/U_T} - 1\right) - \alpha_F I_{ES}\left(e^{-U_{BE}/U_T} - 1\right)$$

$$I_E = I_{ED} - \alpha_R I_{CD} = I_{ES}\left(e^{-U_{BE}/U_T} - 1\right) - \alpha_R I_{CS}\left(e^{-U_{BC}/U_T} - 1\right)$$

larg signal current gains :-

Consider npn :-

* if J_E f.b & J_C reverse biased by

$U_{BC} = 0.$

$$I_E = -I_{ED} = -I_{ES}\left(e^{U_{BE}/U_T} - 1\right)$$

$$I_C = \alpha_F I_{ED} = -\alpha_F I_E \Rightarrow \alpha_F = \frac{I_C}{I_E}$$

$\alpha_F \triangleq$ common base forward short-circuit current gain

⊛ if J_C f.b & J_E reverse biased by $U_{BE} = 0$

$$I_E = -\alpha_R I_{CD}, \; I_C = I_{CD} \Rightarrow I_E = -\alpha_R I_C$$

$$\Rightarrow \alpha_R = \left.\frac{-I_E}{I_C}\right|_{U_{BE}=0}, \quad \alpha_R \triangleq \text{common base}$$

reverse short circuit current gain

Nate :-

I_C, I_E do I_B

$$I_B = -(I_C + I_E)$$

* if J_E is forward.b & $V_{BC} = 0$

$$I_B = -(I_C + I_E) = -(1-\alpha_F) I_E$$

Subject: ____________ / /

$$\Rightarrow \bar{I}_E = \frac{1}{1-\alpha_F} I_B$$

$$I_C = \frac{\alpha_F}{1-\alpha_F} I_B = \beta_F \bar{I}_B$$

$$\beta_F \triangleq \left.\frac{\bar{I}_C}{\bar{I}_B}\right|_{V_{BC}=0} \triangleq$$ common Emitter forward short circuit current gain

* if J_C f.b & $V_{BE}=0$

$$I_B = -(\bar{I}_E + \bar{I}_C) = -(1-\alpha_R)\bar{I}_C \Rightarrow \bar{I}_C = \frac{-1}{1-\alpha_R} \bar{I}_B$$

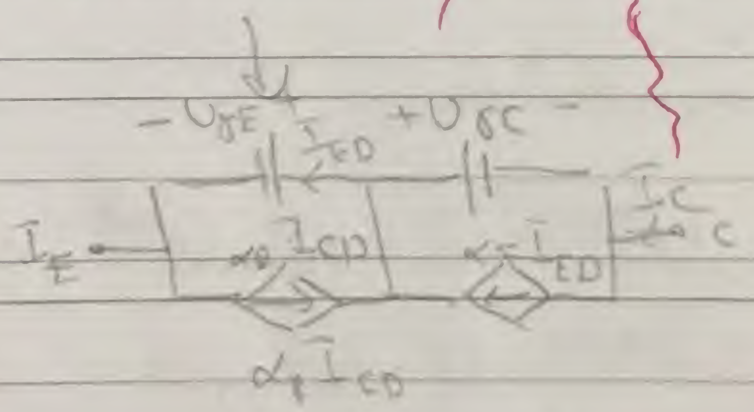
$$\bar{I}_E = \frac{\alpha_R}{1-\alpha_R} I_B = \bar{I}_E = \beta_R \bar{I}_B$$

$$\beta_R = \left.\frac{\bar{I}_E}{\bar{I}_B}\right|_{V_{BE}=0}$$ = Common Emitter Reverse short circuit current

Region of operation of BJT :-

Subject: ____________ / /

Region	J_E	J_C	action
cut-off	R.B	R.B	I_E & I_C in order of Reverse saturation (current ≈ 0) acts as open circuit
forward active	F.B	F.B	BJT acts as CCCS (Amplifire)
Inverse active	R.B	F.B	
saturation	F.B	F.B	$V_{CE} = V_{CE\,sat} = V_{\gamma E} - V_{\gamma C} \cong 0.2V$ BJT acts as (closed swich



$V_{CE} = V_{\gamma E} - V_{\gamma C}$

saturation $= V_{CE\,sat}$

Subject:

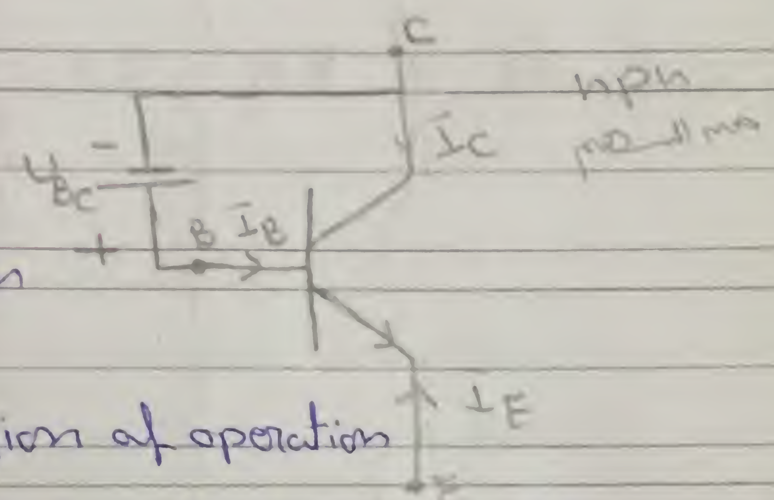
* السهم طالع من القاعدة (npn)

* السهم داخل الى القاعدة (pnp)

Example :-

$V_{BC} < 0$,

Emmitter is open



a// Determine region of operation

b// Determine Base & collector currents

BJT is npn

a// $I_E = 0$, $V_{BC} < 0$ $\Rightarrow$ J_C is R.b

$\Rightarrow$ Region of operation is either cutt-of or forward active.

$$I_E = 0 = -I_{ED} + \alpha_R I_{CD}$$

$$= -I_{ES}\left(e^{V_{BE}/V_T} - 1\right) + \alpha_R I_{CS}\left(e^{V_{BC}/V_T} - 1\right)$$

$$= -I_{ES}\left(e^{V_{BE}/V_T} - 1\right) - \alpha_R I_{CS} = 0$$

$$e^{V_{BE}/V_T} = 1 - \frac{\alpha_R I_{CS}}{I_{ES}} = 1 - \alpha_F$$

Subject: ______ / /

$\Rightarrow \quad (1-\alpha_F) < 1$

$e^{V_{BE}/V_T} < 1 \quad \Rightarrow \quad V_{BE} < 0$

$\Rightarrow J_E$ is R.B

$\Rightarrow$ Region of operation is cut-off

b// $I_C = \alpha_F I_{ES} \left(e^{V_{BE}/V_T} - 1\right) - I_{CS}\left(e^{V_{BC}/V_T} - 1\right)$

$= +\alpha_F I_{ES} \left(e^{V_{BE}/V_T} - 1\right) + I_{CS}$

$= +\alpha_F I_{ES} \left(-\dfrac{\alpha_R I_{CS}}{I_{ES}}\right) + I_{CS}$

$= (1 - \alpha_R \alpha_F) I_{CS} = I_{CO}$ (Reverse collector current

$I_B = -I_C = -I_{CO}$

c// let $I_{ES} = 1fA$, $I_{CS} = 2fA$, $\alpha_{FF} = 99$

find V_{BE}, I_C

Subject: ______ / /

$$e^{v_{BE}/v_T} = 1 - \alpha_F = 0.01 \Rightarrow v_{BE} = v_T \ln 0.1$$

$$= -0.115V$$

$$\alpha_R I_{CS} = \alpha_F I_{ES} \Rightarrow \alpha_R = \frac{\alpha_F I_{ES}}{I_{CS}} = \frac{0.99 * 1fA}{2\,fA}$$

$$= 0.495$$

$$\therefore I_C = I_B = (1 - \alpha_R \alpha_F) I_{CS} = 1.02\ fA$$

* The common base (CB) characteristics:-

- input characteristics :- I_E in terms of v_{BE}, v_{BC}
- output characteristics :- I_C in terms of I_E, v_{BC}

consider an npn :-

(*) output characteristic

$$(1) \text{-----} I_E = -I_{ES}(e^{v_{BE}/v_T} - 1) + \alpha_R I_{CS}(e^{v_{BC}/v_T} - 1)$$

$$(2) \text{---} I_C = -I_{CS}(e^{v_{BC}/v_T} - 1) + \alpha_F I_{ES}(e^{v_{BE}/v_T} - 1)$$

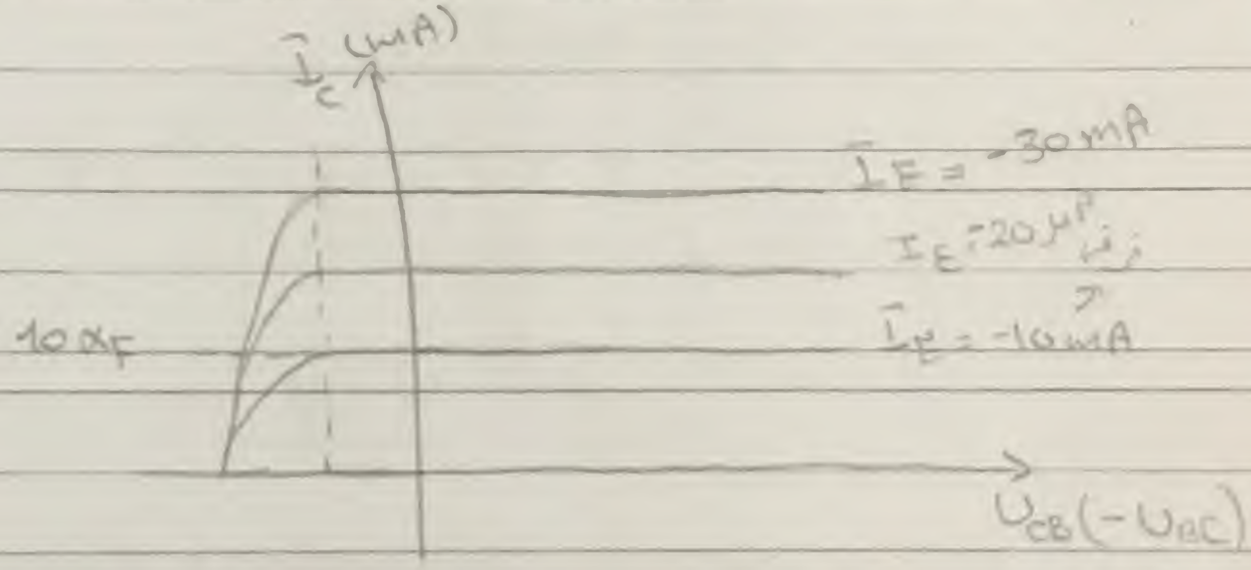
form (1) $I_{ES}(e^{v_{BE}/v_T} - 1) = I_E + \alpha_R I_{CS}(e^{v_{BC}/v_T} - 1)$

$$= -(1 - \alpha_R \alpha_F) I_{CS}(e^{v_{BC}/v_T} - 1)\ \alpha_F I_E$$

Subject: ______________   /   /

output characteristic

$$\boxed{I_C = I_{CO}\left(e^{V_{BC}/V_T} - 1\right) - \alpha_F I_E}$$



— The forward active region

— $I_C \cong -\alpha_F I_E \Rightarrow I_C$ independent of V_{BC}
depends only I_E

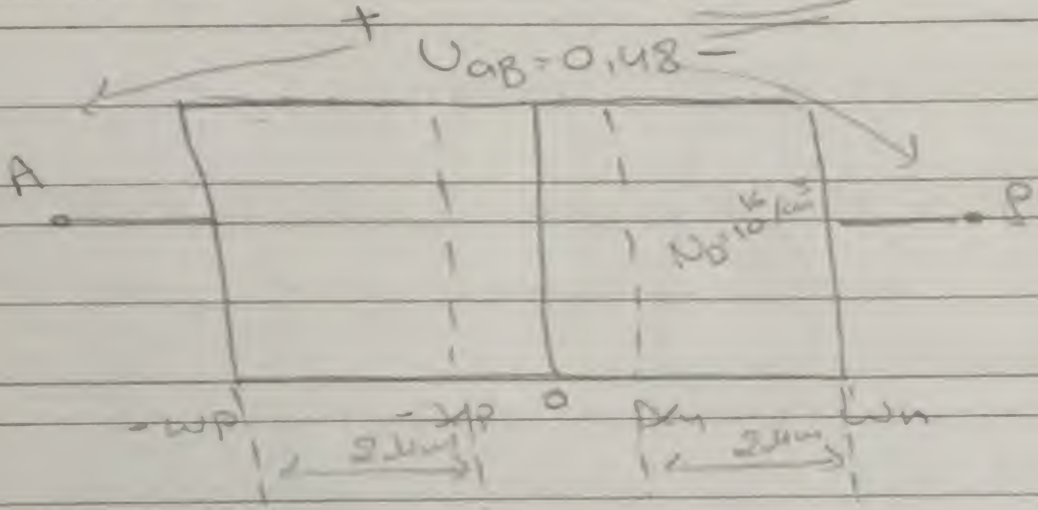
$\underset{\alpha=1}{\cong} -I_E$

— $I_E = 0 \rightarrow I_C = -I_{CO}$ (cut-off)

Subject: ______ / /

PS #4 forward biased $v_B > 0$

Problem "7" $N_D = 10^{16}$



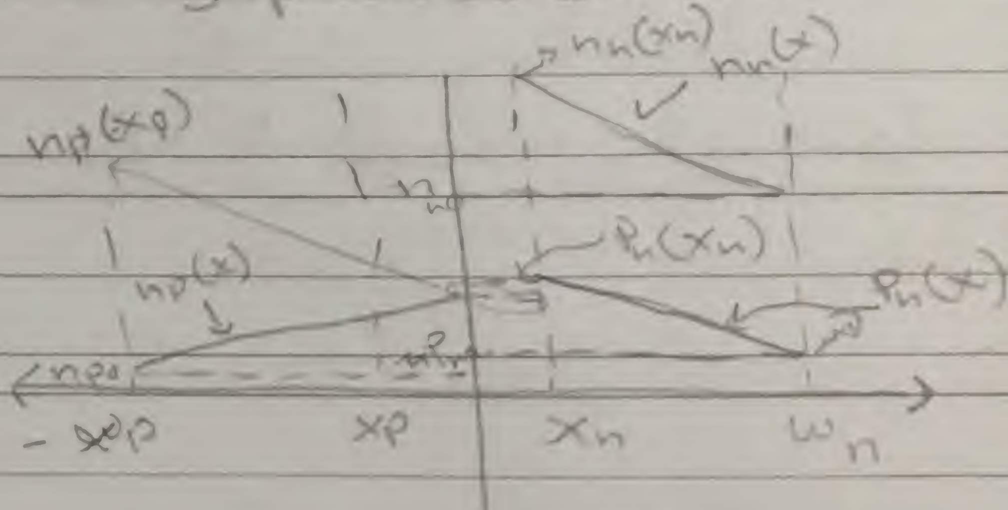
$\Rightarrow x_p = x_n \cong 0$, $L \gg 2\mu m \Rightarrow L_p \gg w_n$

$L_n \gg w_p$

$\Rightarrow$ it is a short circuit diode

$\mu_n = 1600\ cm^2/V.s$

$\mu_p = 600\ cm^2/V.s$



Subject: ________________ / /

$$a//(i)\; P_n(w_n) = P_{n0} = \frac{n_i^2}{N_D} = \frac{2.25\times10^{20}}{10^{16}}$$

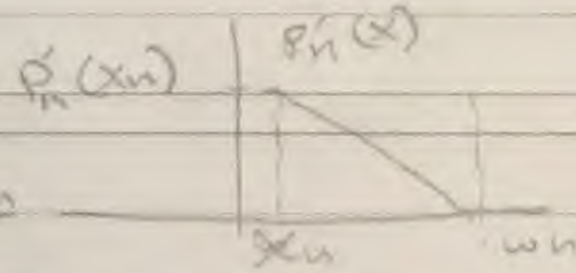
$$= 2.25\times10^{4}\ \text{holes}/cm^3$$

$$(ii)\quad P_n(x_n) = P_{n0}\, e^{V_D/V_t} = 2.25\times10^{4}\, e^{480/25}$$

$$\left.\begin{aligned} P_n(x) &= P_{n0} + P'_n(x) \\ n_n(x) &= n_{n0} + n'_n(x) \end{aligned}\right\} P'_n(x) = n'_n(x)$$

$$(iii)\quad \rho_p(x) = q\,P'_n(x) \Rightarrow Q'_p = \int_{x_n}^{w_n} \rho_p(x)\, d\underset{\text{volume}}{v}$$

$$= \int_{x_p}^{w_n} \rho_p(x)\, A\,dx = Aq \int_{x_n}^{w_n} P'_n(x)\,dx$$



$$Q'_p = q A P'_n(x_n)\frac{w_n - x_n}{2}$$

$$= qA P'_n(x_n)\frac{w_n}{2} \rightarrow \text{مساحه المثلث}$$

$$= 3.428\ fC$$

Subject: / /

iv) $J_p(0) = J_p(x_n) = -q D_p \frac{d}{dx}(P_n(x))$

$= -q D_p \frac{d}{dx}(P_n'(x))$

$\approx -q D_p \frac{\overset{\approx 0}{P_n'(w_n)} - P_n'(x_n)}{\underset{\approx 0}{w_n - x_n}}$

$= \frac{q D_p P_n'(x_n)}{w_n} = 26.16 mA/cm^2$

(B) $n_p(-x_p) = P_n(x_n)/10$

(i)

$n_p(-x_p) = n_{p0} e^{v_0/v_T} \Rightarrow n_{p0} = n_p(-x_p) e^{-v_0/v_T}$

$= \frac{P_n(x_n)}{10} e^{-v_0/v_T} = 2.18 \times 10^{12} e^{-\frac{480}{25}}$

$\approx 10^3/cm^3$

$\Rightarrow N_A = n_i^2/n_{p0} = 2.25 \times 10^{17}/cm^3$

Subject: ______________ / /

(ii) $Q_n' = qA\,n_p'(-x_p)\,\frac{w_n}{2} = 0.3488\,fC$

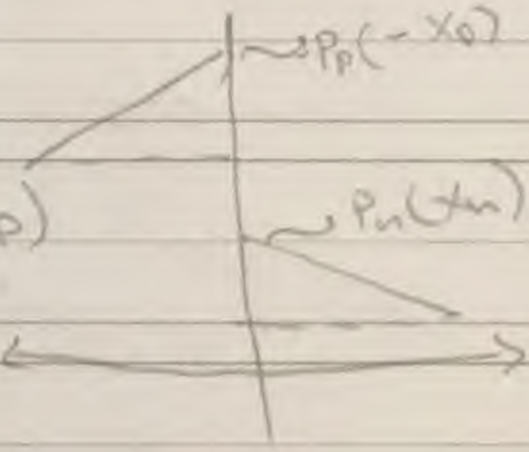
(iii) $J_n(0) = J_n(-x_p) = qD_n \frac{dn_p(x)}{dx} = qD_n \frac{dn_p'(x)}{dx}$

$$= qD_n \frac{n_p'(-x_p) - n_p'(-w_n)}{-x_p - (-w_n)}$$

$$= qD_n \frac{n_p'(-x_p)}{w_n} = 6.97\ mA/cm^2$$

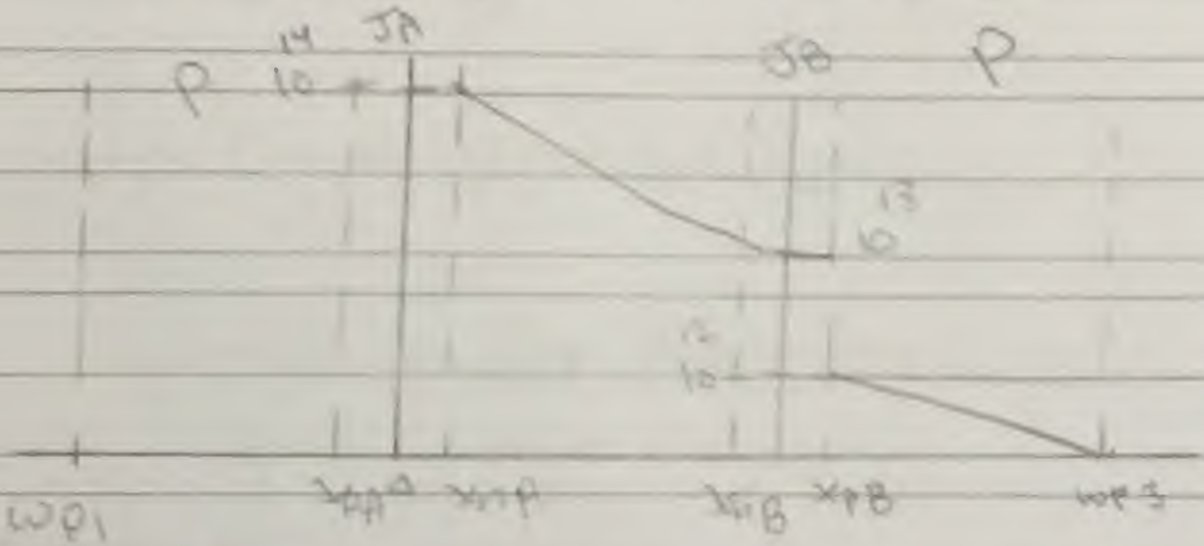
(iv)

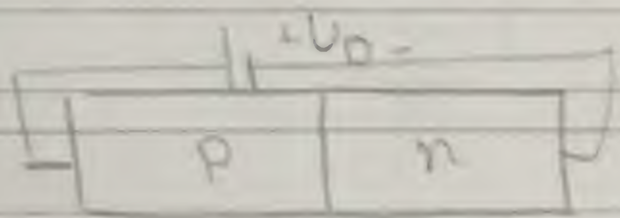
$$\phi = V_T \ln \frac{p_n(x_n)}{p_p(-x_p)}$$



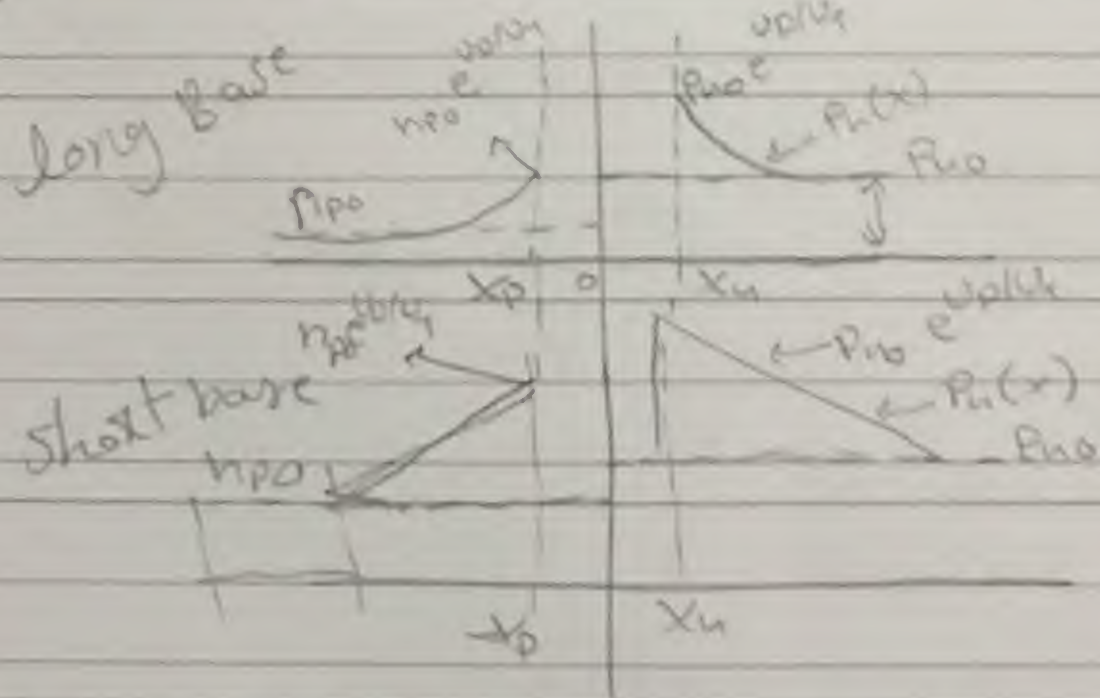
Subject: ______ / /

Problem (8) :-





VD>0



لما نغير الـ سالب بالموجب junction صارت هالـ forward لو العكس صارها reverse

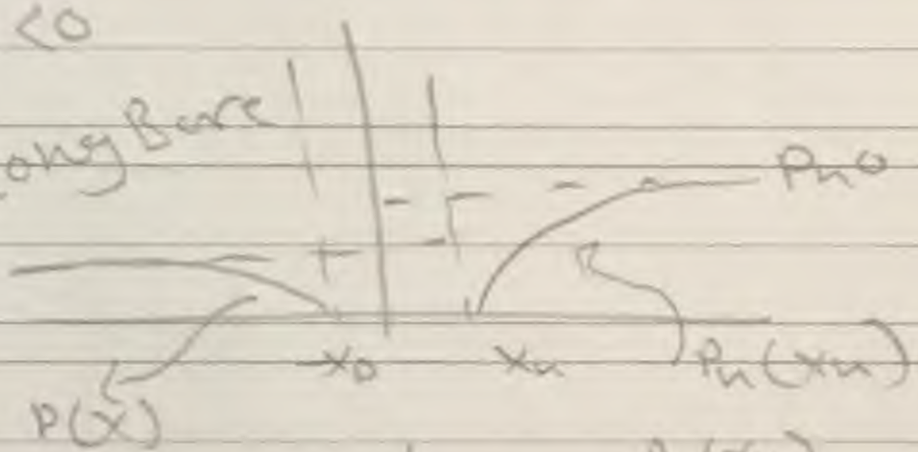
Subject: / /

$$p_n'(x_{nB}) = p_{n0} e^{V_{DB}/V_T} - p_{n0} = 10^{13}$$

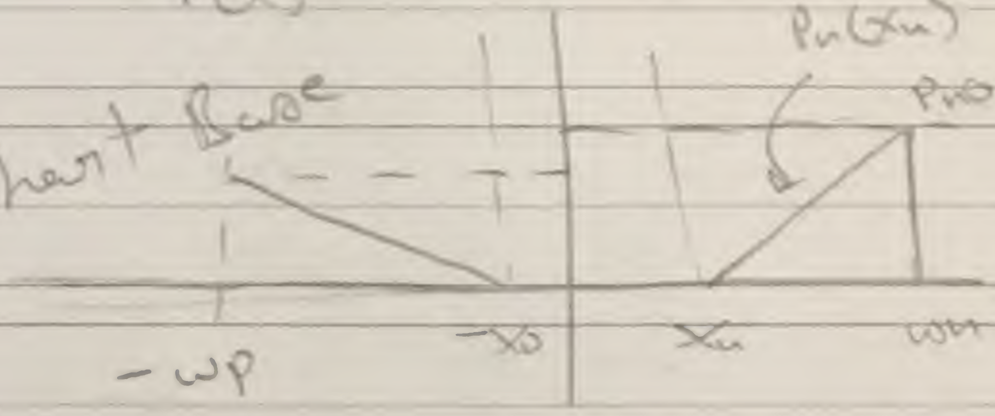
$$p_n'(x_{nA}) = p_{n0} e^{V_{DA}/V_T} - p_{n0} = 10^{14}$$

$V_D < 0$

long Base



short Base

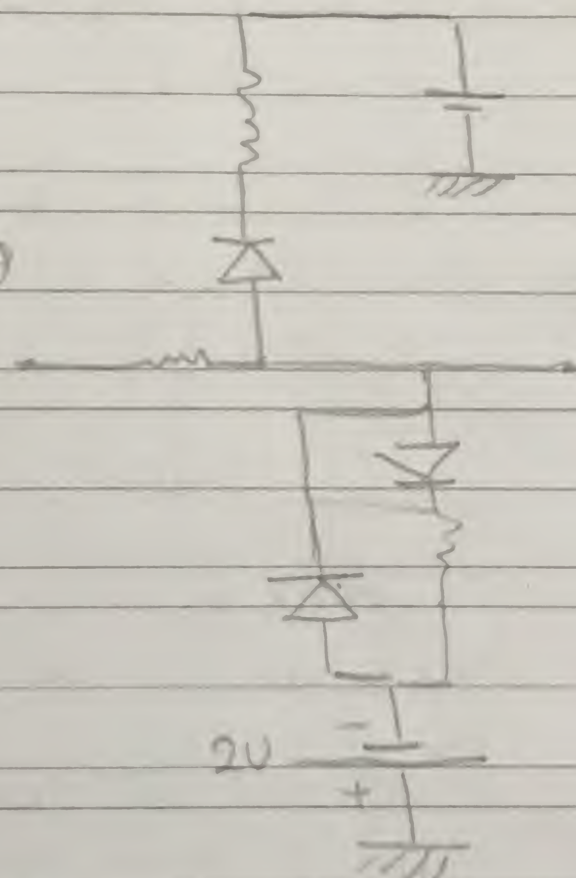


Subject: ____________ / /

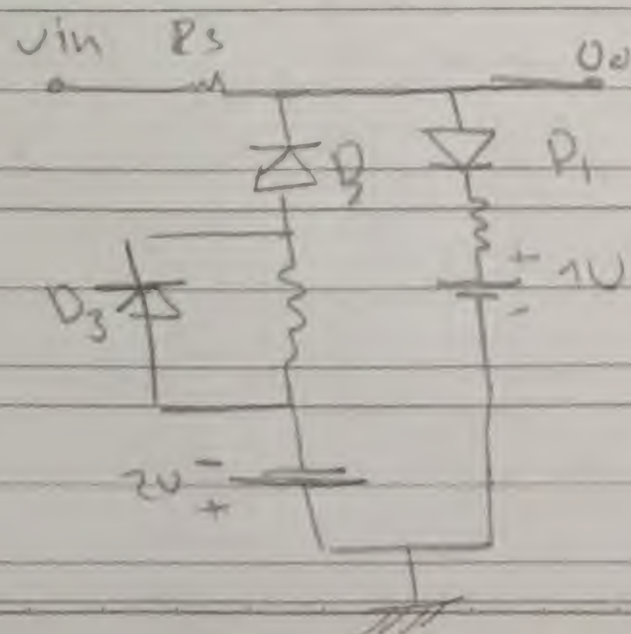
PS#5

P(9)

① →

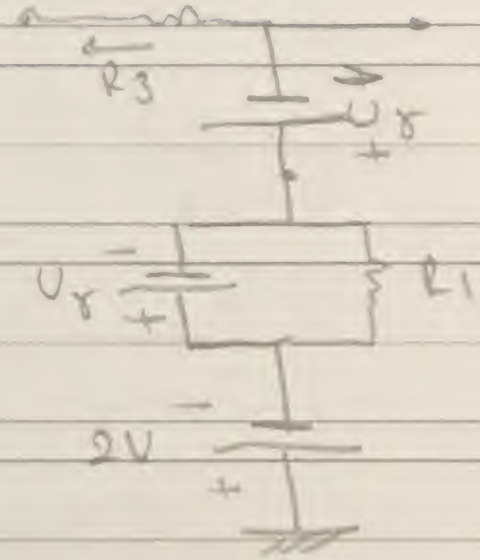


②



Subject: ______________ / /

when D_1 off, D_2 & D_3 ON



$V_o = -2-2V_\gamma = -3.4V$

for $V_o \geq V_{in} \Rightarrow$ for $V_{in} \leq -3.4V$

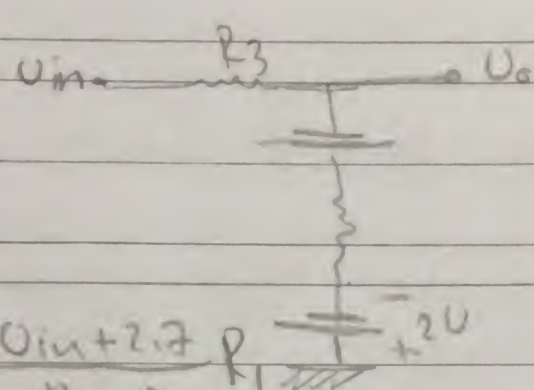
$I = \dfrac{V_\gamma}{R_1} \Leftarrow V_\gamma$ open $\Leftarrow$ لما التيار، بيقل

$$\frac{-3.4 - V_{in}}{R_3} = \frac{V_\gamma}{R_1}$$

$$-3.4 - V_{in} = \frac{V_\gamma R_3}{R_1}$$

$$V_{in} = -3.4 - \frac{V_\gamma R_3}{R_1}$$

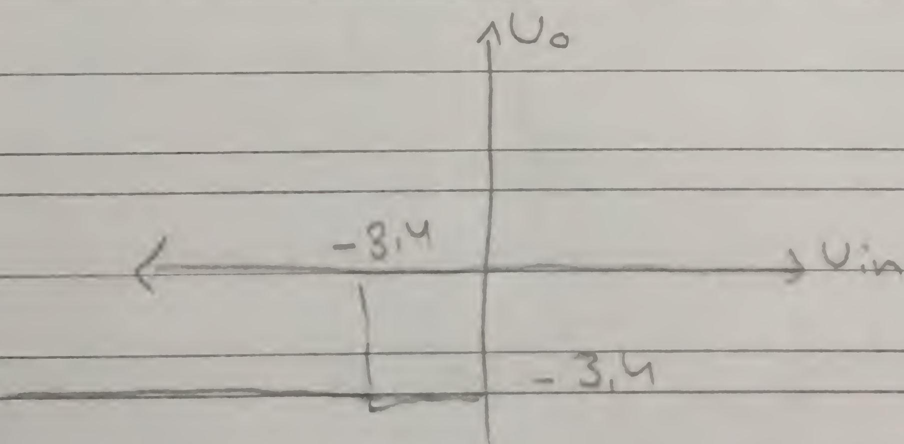
Subject: ______________ / /



$v_{in} > -3.4$

$v_o = 2.7 + \frac{v_{in}+2.7}{R_1+R_3} R_1$

$= -2.7 + \left(\frac{v_{in}+2.7}{4}\right) R_1$



Subject: ________ / /

clipping دائرة القص
clamping دائرة التثبيت

Subject: ______ / /

23/5/2017

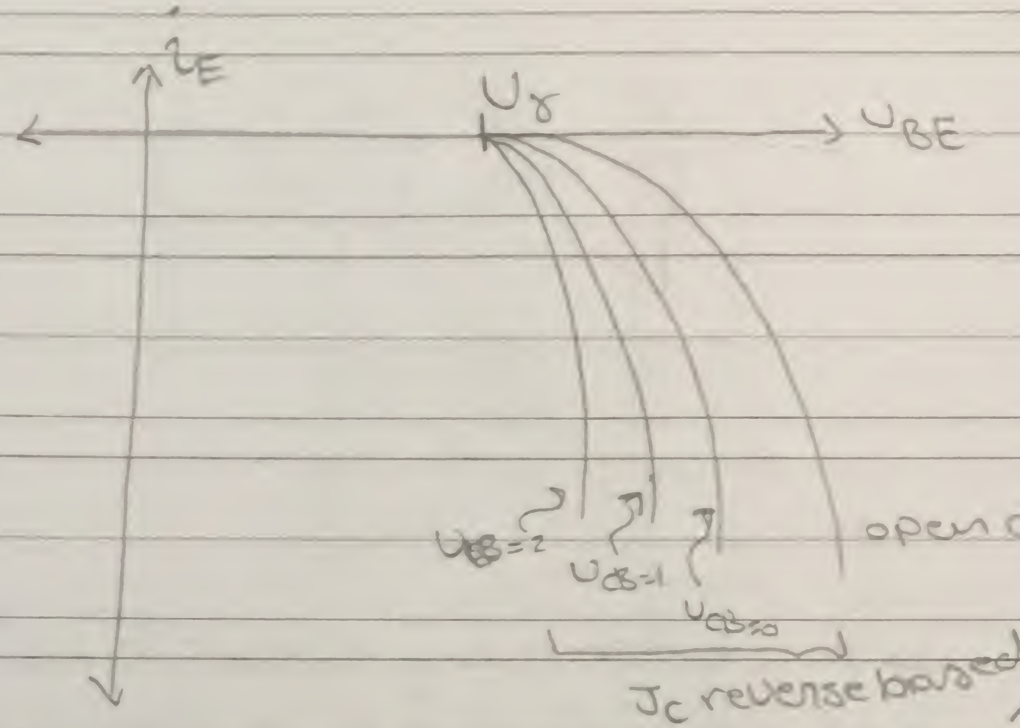
* The input characteristics :-

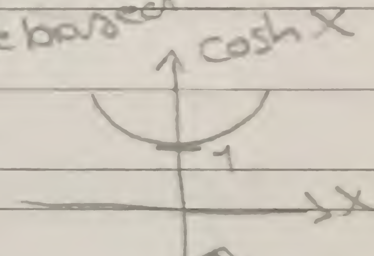
Plot of I_E versus V_{BE} for different values of V_{CB}

⇒ it is the characteristic of Base-Emitter diod at different base collector voltages

$|i_E|$ increases as the reverse bias of the collector junction increased

Subject: ______________ / /





- why ?

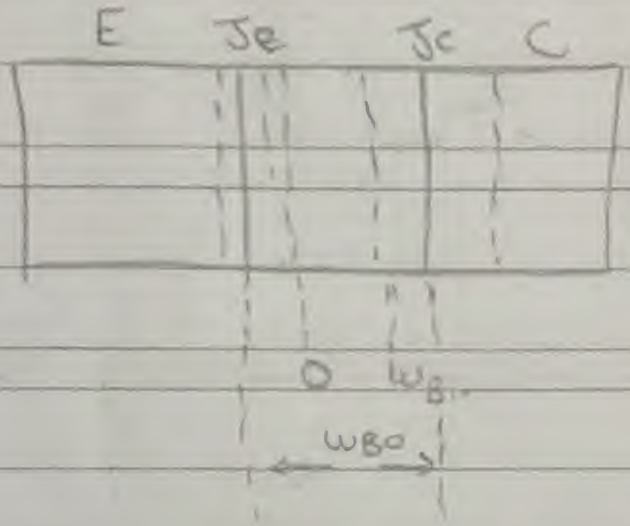
1- we know that $\alpha_F = \gamma \alpha_T M$

α_T = base Transission factor = $\frac{1}{\cosh(w_B/L_B)}$

$w_B \triangleq$ effictive Base width

$L_B \triangleq$ Diffusion leght of minority carriers in base region E&C have higher doping level Than B.

Subject: **Short Base straight line**



with increasing reverse bias of J_c

$\Rightarrow$ base width (W_B) increases

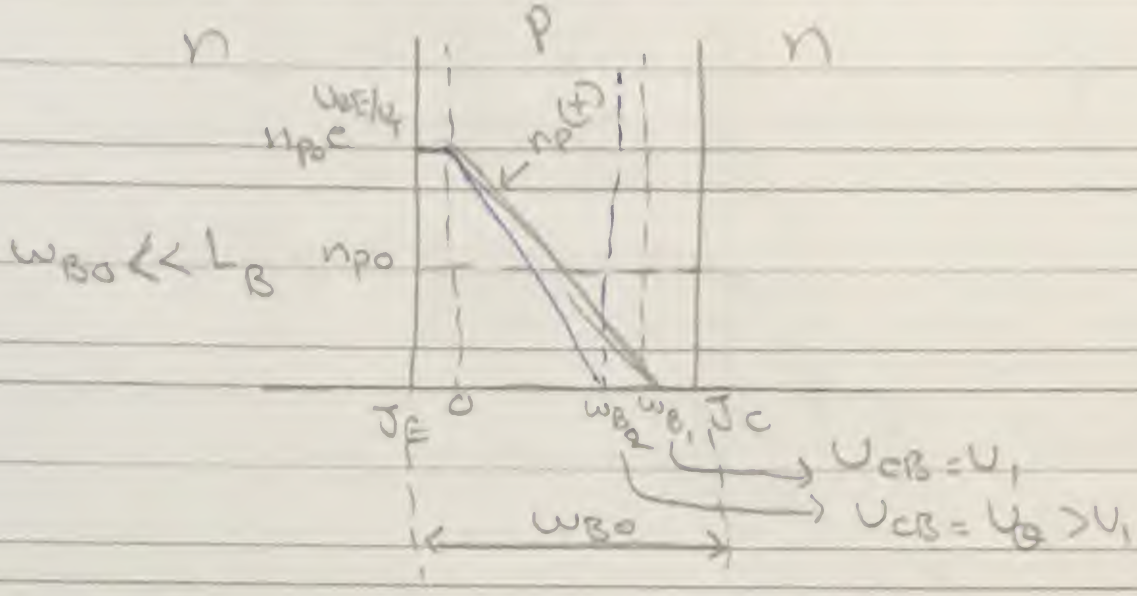
$\Rightarrow \alpha_T$ increases

$\Rightarrow \alpha_F$ increases

$\Rightarrow$ magnitude of I_c slightly increases with increasing reverse bias of J_c

2 - concentration gradient of minority carriers in base region

Subject: / /



- increasing reverse bias of J_C

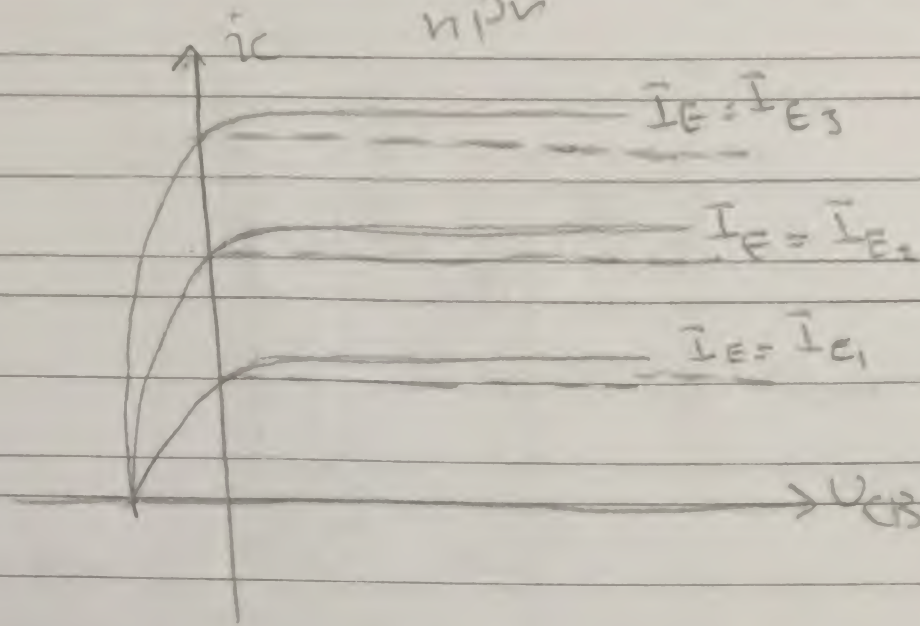
  $\Rightarrow$ magnitude of concentration gradient of minority carrieres in base region increases

  $\Rightarrow$ diffusion current increases with creasing reverse bias of J_C

  $\Rightarrow$ I_E increases with increasing reverse bias of J_C

Subject: ____________ / /

npn



$|I_{E3}| > |I_{E2}| > |I_{E1}|$, $I_{E1} < 0$, $I_{E2} < 0$, $I_{E3} < 0$

The Effictive base width of the base is given by :-

for npn
for pnp

$$\omega_B = \omega_{B0} - \left[\frac{2\epsilon}{qN_B}(\phi_{oc} - V_{BC})\right]$$

N_B = Base doping level

The prunch Through valtage

V_{PT} = value of J_c reverse bias that reduces Effictive base width

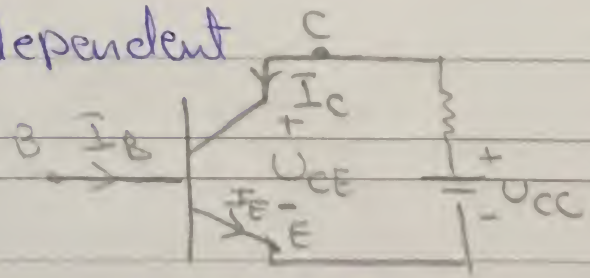
Subject: ______________ / /

w_B to zero casing Breakdown of BJT

$$w_B = w_{B0} - \left[\frac{2\epsilon}{qN_B}\left(\phi_{oC} + V_{RT}\right)\right]$$

- Common Emitter characteristics:-

- I_B & V_{CE} are the independent values

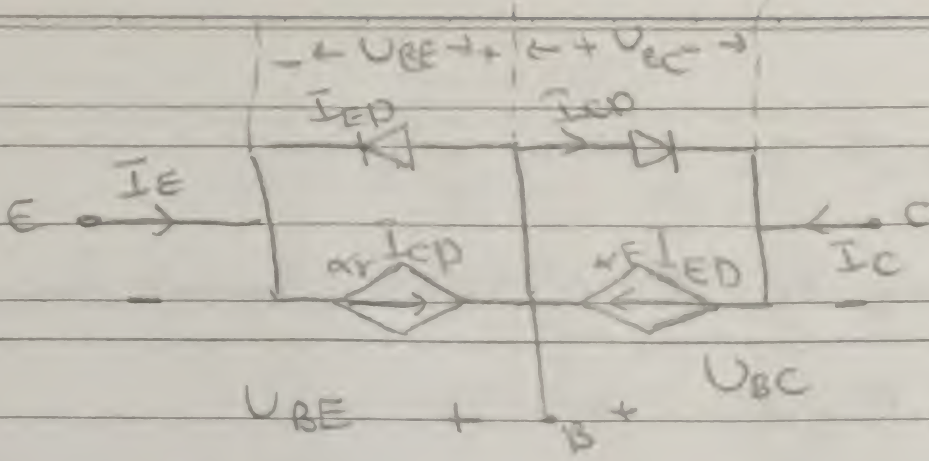


- I_C, V_{BE} are the dependent values

$$I_C = f_1(I_B, V_{CE}),\quad V_{BE} = f_2(I_B, V_{CE})$$

$$V_{CE} = V_{CB} + V_{BE} = V_{BE} - V_{BC}$$
$$= V_{BE} -$$

Subject: ______________ / /



with J_E f.b & J_C R.b

$$\Rightarrow I_E = -I_{ED}, \quad I_C = \alpha_F I_{ED} \overset{+I_{Co}}{} = -\alpha_F I_E \overset{+I_{Co}}{}$$

$$I_B = -(I_C + I_E) = -(1-\alpha_F) I_E$$

$$I_E = \frac{-1}{1-\alpha_F} I_B, \quad I_C = -\alpha_F I_E + I_{CO}$$

$$\therefore I_C = -\alpha_F I_E + I_{CO}$$

$$= -\alpha_F [-(I_B + I_C)] + I_{CO}$$

$$I_C = \alpha_F (I_B + I_C) + I_{CO}$$

$$I_C (1-\alpha_F) = \alpha_F I_B + I_{CO}$$

$$I_C = \underbrace{\frac{\alpha_F}{1-\alpha_F}}_{\beta_F} I_B + \underbrace{\frac{1}{1-\alpha_F}}_{(1+\beta_F)} I_{CO}$$

Subject: ________ / /

[illegible]

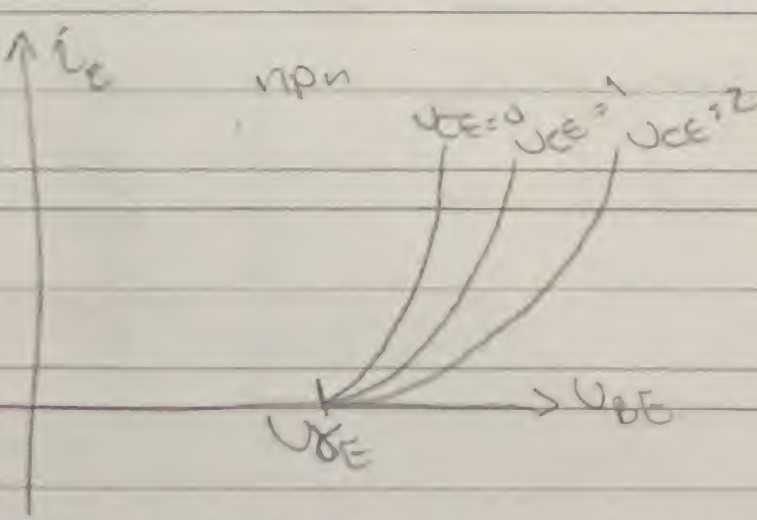
$$I_C = \beta_F I_B + (1+\beta_F) I_{CO}$$

The dc forward current gain is defind

$$h_{FE} \triangleq \frac{I_C}{I_B} \cong \beta_F$$

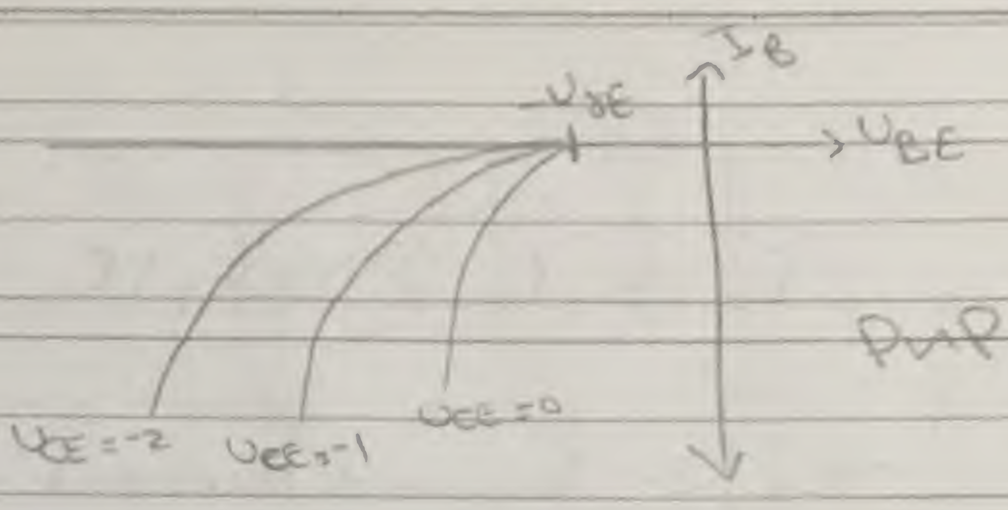
CE input characteristics :-

I_B Vs. V_{BE} for different V_{CE}



← لما تزيد V_{CE} معناها تزيد في الانحياز العكسي

Subject: ____________ / /



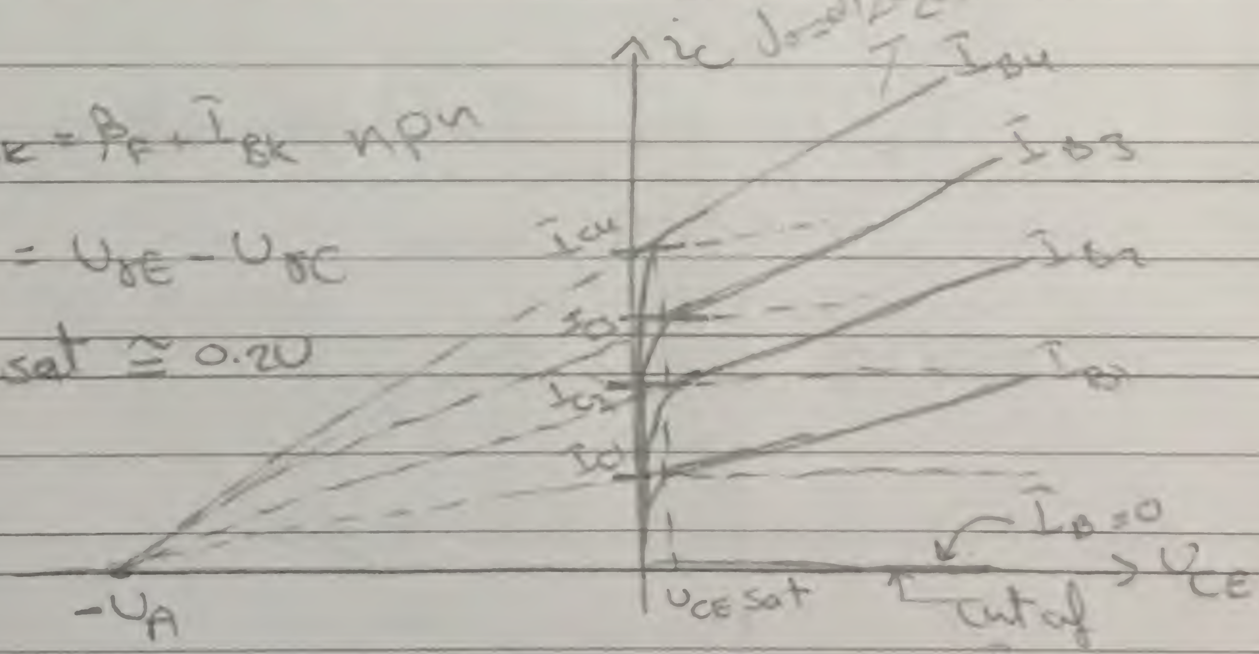
CE output characteristics :-

I_C vs V_{CE} , I_B as parameter

$I_{CK} = \beta_F \cdot I_{BK}$ npn

$= V_{\gamma E} - V_{\gamma C}$

V_{CE} sat $\cong 0.2V$

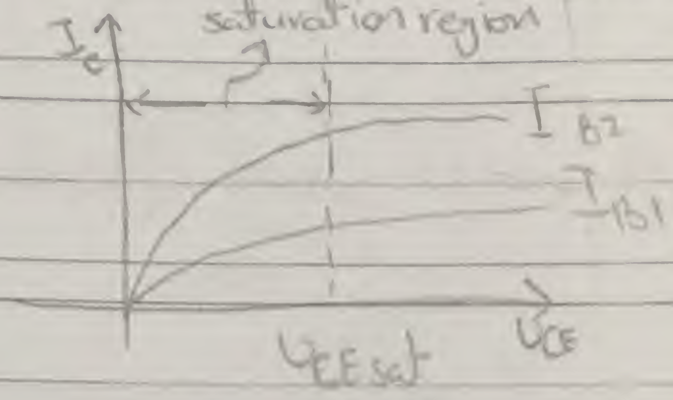


$V_A \triangleq$ early voltage

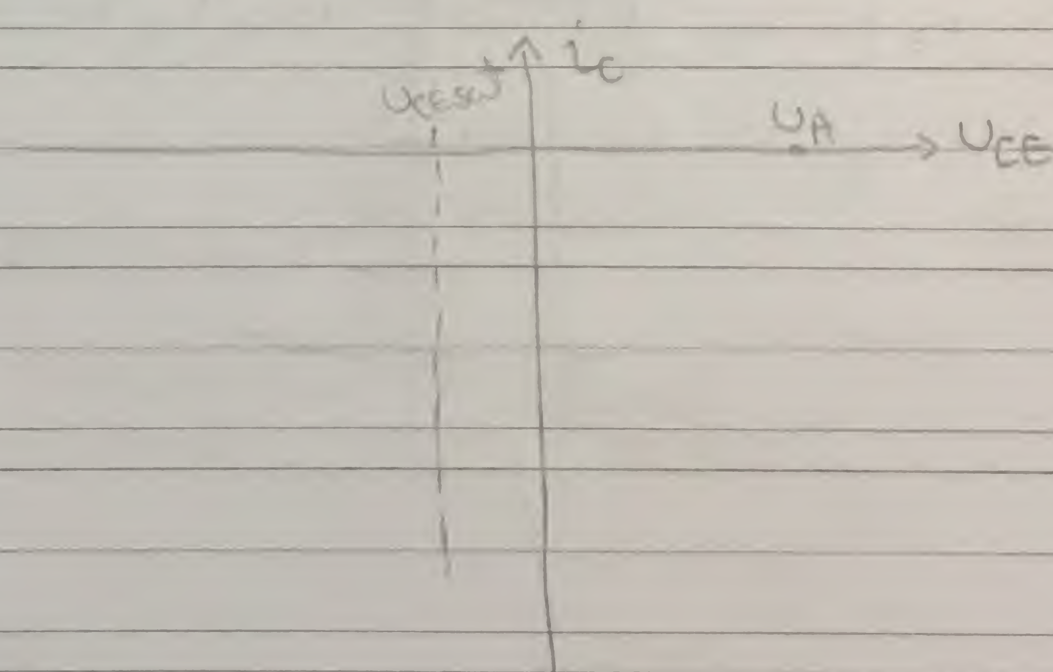
+ve slope of curves due to base width modulation

Subject: ______ / /

$U_{CE} \leq U_{CEsat}$



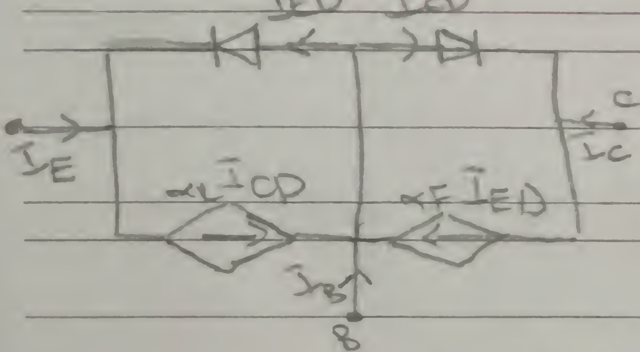
* ملاحظة الميول لأن U_A تكون كبيرة جدا
أي أن الميول بسيط جداً (تكاد تكون خط مستقيم)

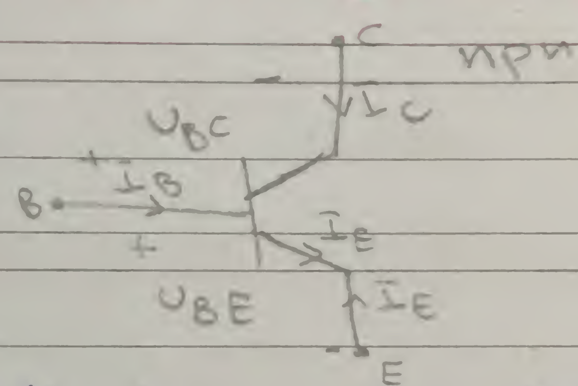


Subject: ______________ / /

2017/5/30

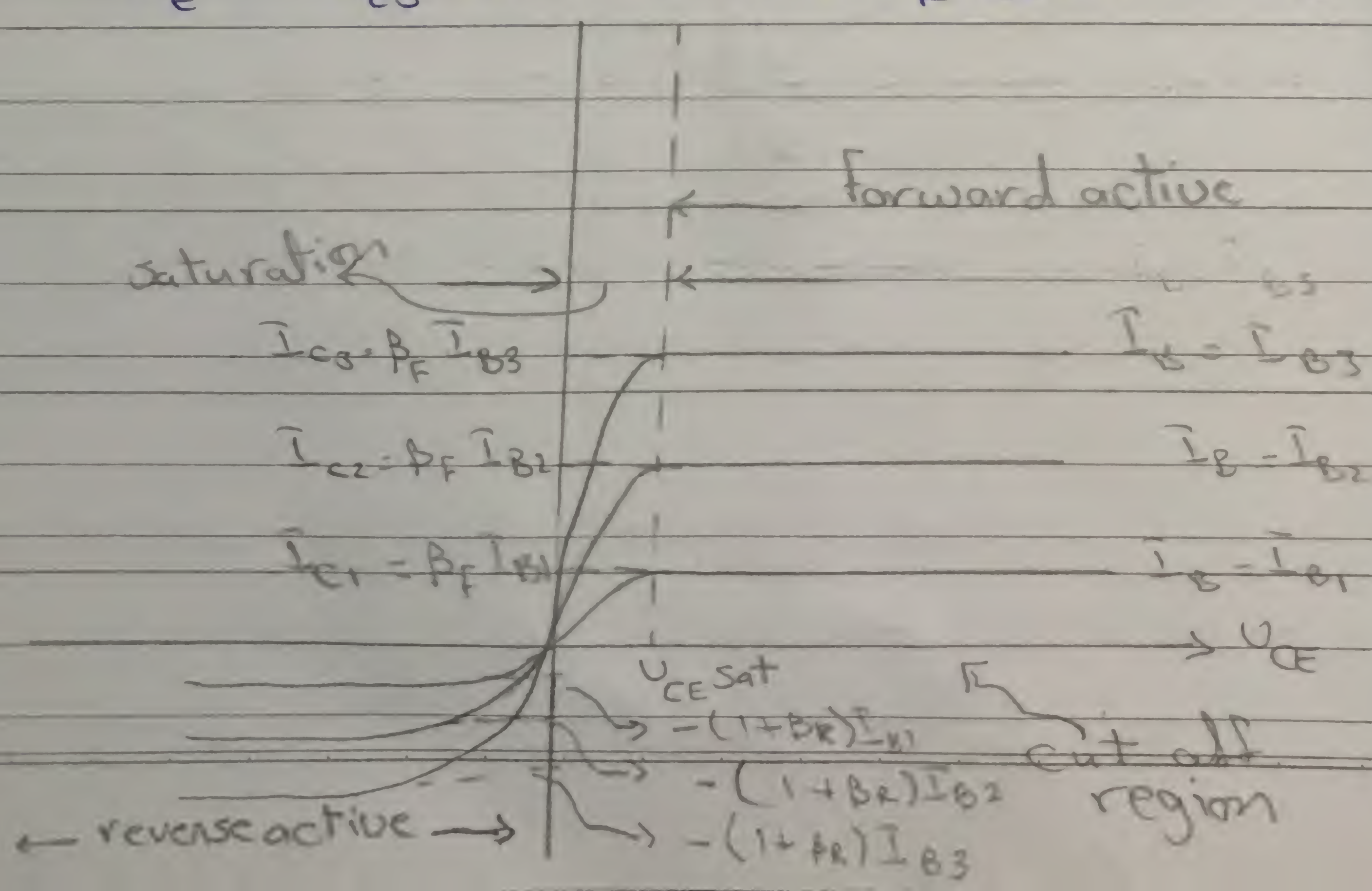
BJT models in the 4-regions of operation



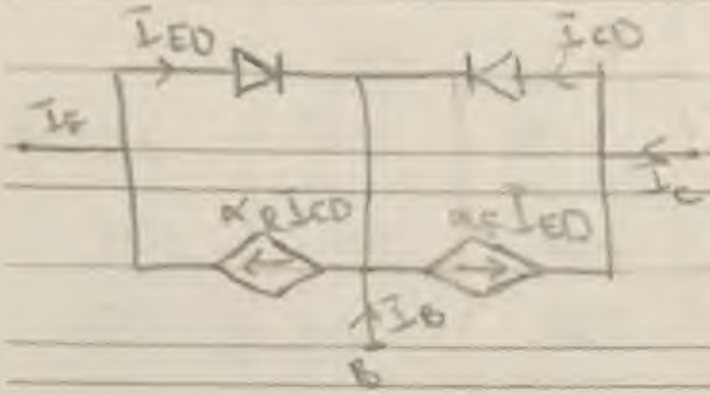


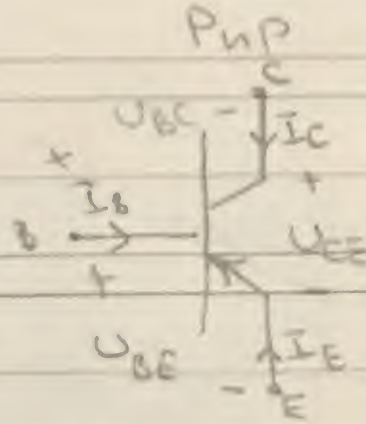
$$I_C = -I_{CS}\left(e^{U_{BC}/U_T}-1\right) + \alpha_F I_{ES}\left(e^{U_{BE}/U_T}-1\right)$$

$$I_E = -I_{ES}\left(e^{U_{BE}/U_T}-1\right) + \alpha_R I_{CS}\left(e^{U_{BC}/U_T}-1\right)$$



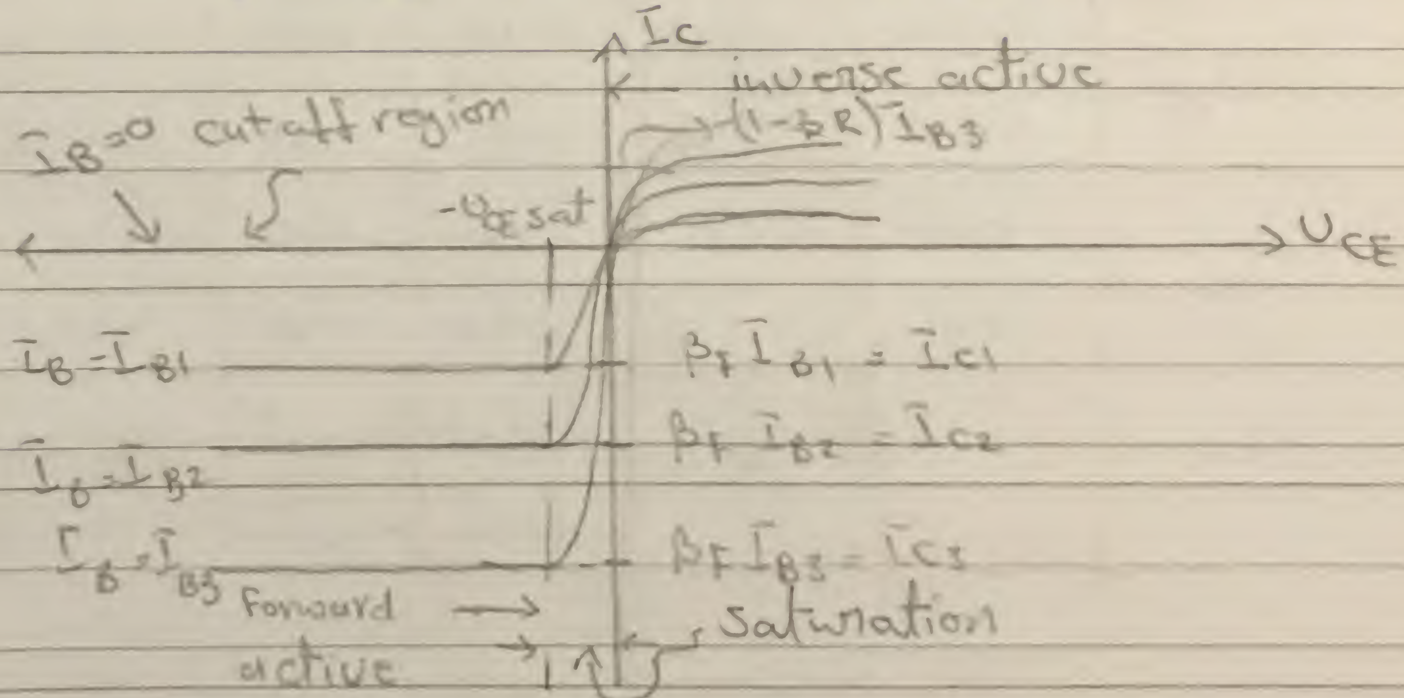
Subject:





$$I_C = I_{CS}(e^{-U_{BC}/U_T} - 1) - \alpha_F I_{ES}(e^{-U_{BE}/U_T} - 1)$$

$$I_E = I_{ES}(e^{-U_{BE}/U_T} - 1) - \alpha_R I_{CS}(e^{-U_B/U_T} - 1)$$



Subject: ____________ / /

* Currents & Voltage polarities

inverse active

		cutoff	F.A	Sat	I.A
I_B	npn	0	>0	>0	>0
	pnp	0	<0	<0	<0
I_C	npn	0	>0	>0	<0
	pnp	0	<0	<0	>0
I_E	npn	0	<0	<0	>0
	pnp	0	>0	>0	<0
V_{BE}	npn	$<V_{\gamma E}$	$V_{\gamma E}$	$V_{\gamma E}$	$<V_{\gamma E}$
	pnp	$>-V_{\gamma E}$	$-V_{\gamma E}$	$-V_{\gamma E}$	$>-V_{\gamma E}$
V_{BC}	npn	$<V_{\gamma C}$	$<V_{\gamma C}$	$V_{\gamma C}$	$V_{\gamma C}$
	pnp	$>-V_{\gamma C}$	$>-V_{\gamma C}$	$-V_{\gamma C}$	$-V_{\gamma C}$
V_{CE}			$>V_{CEsat}$	V_{CEsat}	$<-V_{CEsat}$
			$<-V_{CEsat}$	$-V_{CEsat}$	$>V_{CEsat}$

$V_{CE} = V_{CB} + V_{BE}$

$= V_{BE} - V_{BC}$

$V_{CE_{sat}} = V_{\gamma E} - V_{\gamma C} = 0.7 - 0.5 = 0.2$ for Si

$I_E = -(I_C + I_B)$

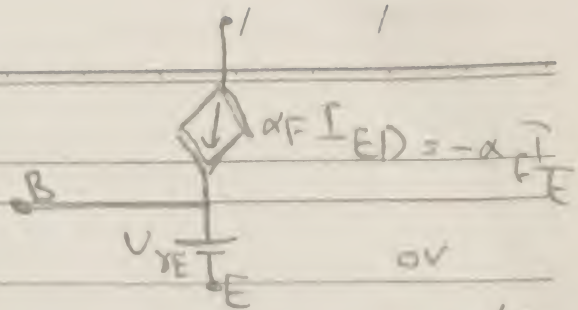
I_E عكس الـ[illegible]

$V_{CE} = V_{CB} + V_{BE} = -V_{BC} + V_{BE} = -V_{\gamma C} + V_{BE}$

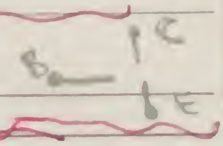
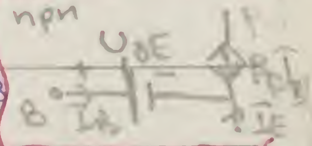
$V_{BE} < V_{\gamma E} \Rightarrow V_{CE} < V_{\gamma E} - V_{\gamma C}$

$< V_{CE\,sat}$

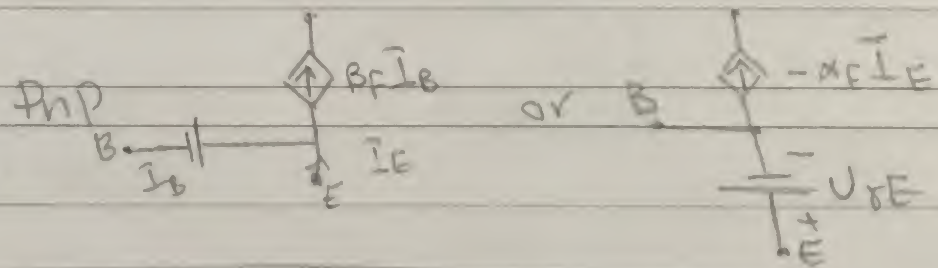
Subject: ______________



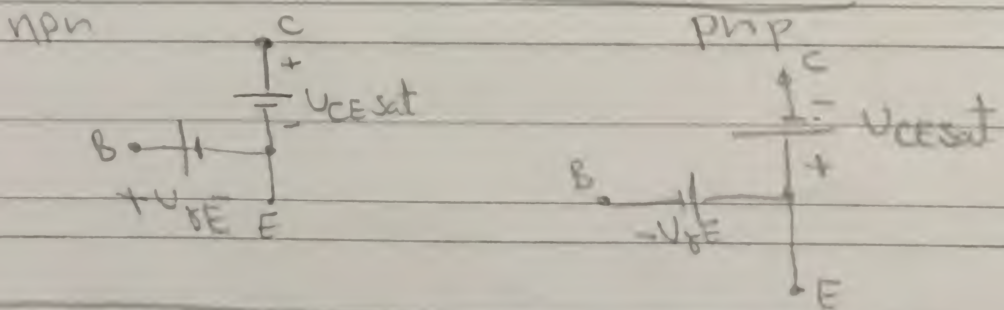
models

Region	J_E	J_C	I_B	I_C	I_E	model
cut off	R.B	R.B	0	0	0	
F.A	F.B	R.B	npn>0 pnp<0	$\beta_F I_B$ independent V_{CE}	$-(1+\beta_F) I_B$	npn 
saturation	F.B	F.B	npn>0 pnp<0	?	$-(I_C+I_B)$	
Inverse active	R.B	F.B	npn>0 pnp<0	$\beta_R I_B$		

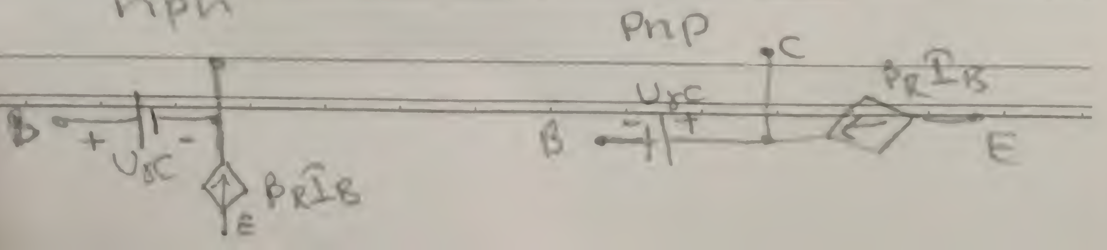
F.A



saturation

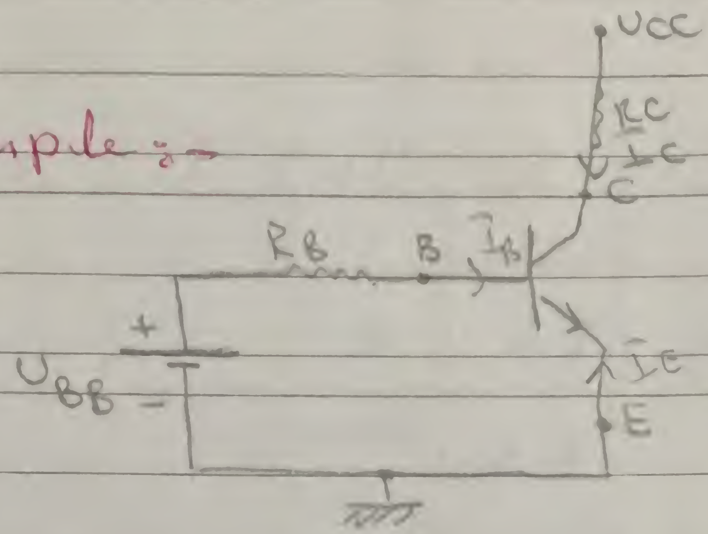


I.A



Subject: ______ / /

Example :-



Let $R_B = 100k\Omega$, $R_C = 4k\Omega$, $V_{CC} = 10V$

$V_{\gamma E} = 0.7V$, $V_{\gamma C} = 0.5V$

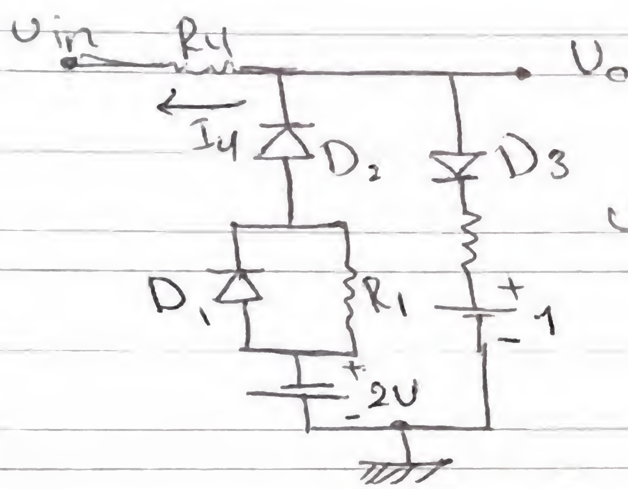
$\beta_F = 100$ $\beta_R = 1$

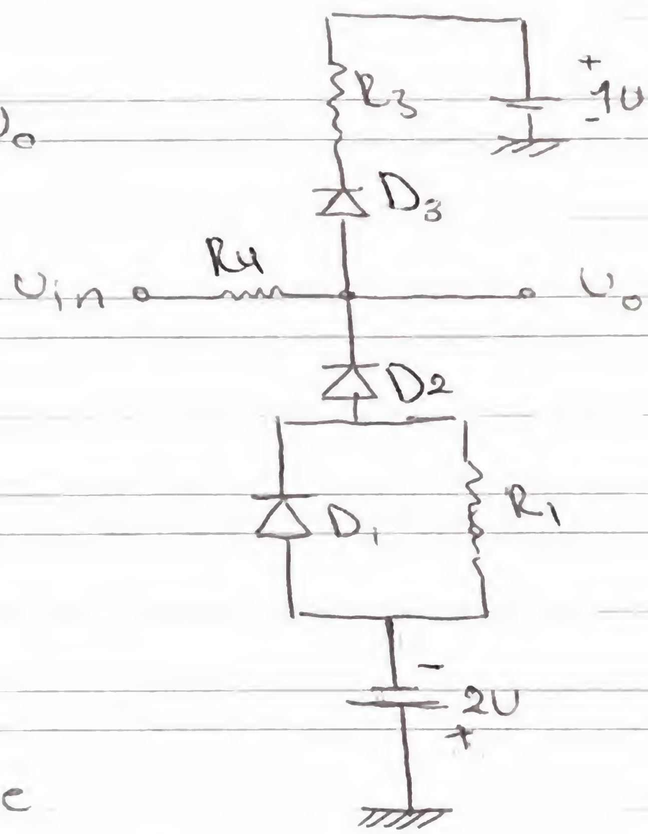
a// for $V_{BB} = 1.7V$ Determine the operating point

Subject: ________ / /

Tutorial

PS #5



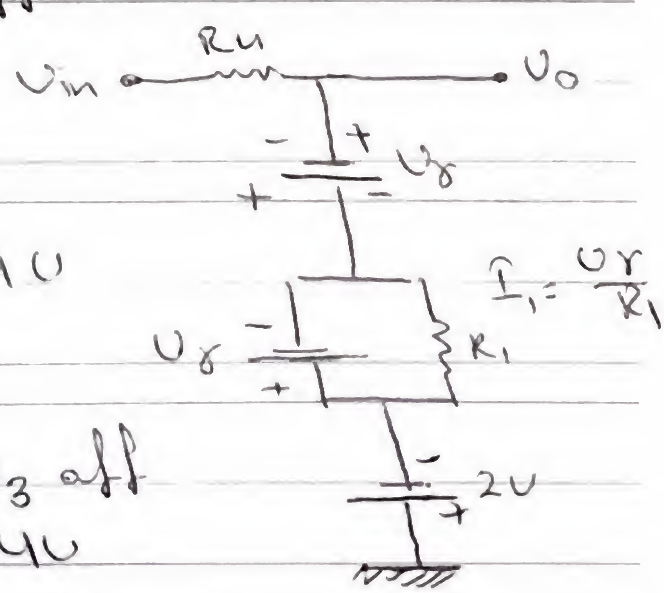


$V_\gamma = 0.7V$

for V_{in} very -ve

D_1 & D_2 on & D_3 off

~~D_3 &~~



$V_o = -2 - 2V_\gamma = -3.4V$

for $V_{in} \leq V_1$

D_1 & D_2 on & D_3 off

$V_o = -3.4V$

Subject: ________ / /

- find v_1 :- @ $v_{in} = v_1 \Rightarrow I_{D_1} = 0$

$$I_4 = I_{D2} \ , \ I_{D2} = I_{D_1} + I_1$$

$$I_4 = \frac{V_o - V_{in}}{R_4} = \frac{-3.4 - V_{in}}{R_4} \text{ for } V_{in} < V_1$$

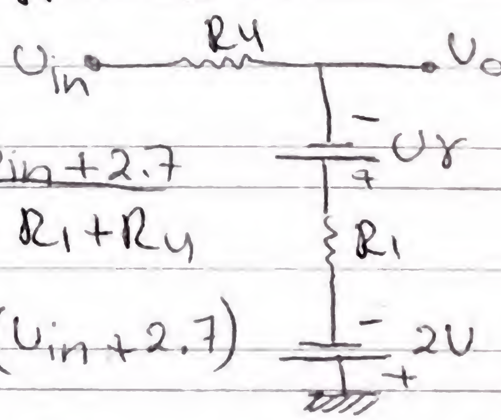
$$V_{in}\uparrow \Rightarrow I_4\downarrow \Rightarrow I_{D2}\downarrow \Rightarrow I_{D_1}\downarrow$$

$$I_4 = I_{D2} = I_1 = \frac{V_\gamma}{R_1}$$

$$V_{in} = V_o - R_4 I_4 = -3.4 - \frac{R_4}{R_1} V_\gamma = -5.5V$$

- for ~~vin~~ $V_1 \leq V_{in} \leq V_2$

D_1 off , D_3 off , D_2 on



$$V_o = -2.7 + R_1 \frac{V_{in} + 2.7}{R_1 + R_4}$$

$$= -2.7 + \frac{1}{4}(V_{in} + 2.7)$$

$$= \frac{1}{4} V_{in} - \frac{8.1}{4} = \frac{V_{in}}{4} - 2.025$$

Subject: ________ / /

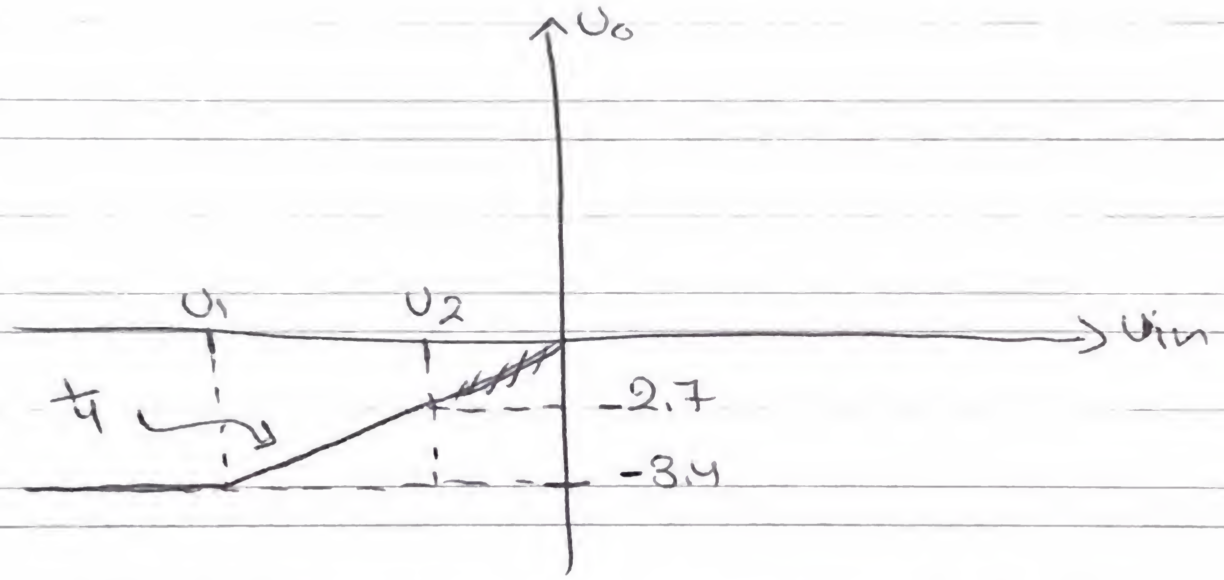
when D_2 Turns off

(a) ~~$v_{in} = v_2$, D_3~~

v_o $I_4 = \dfrac{-2.7 - v_{in}}{R_1 + R_4} = I_{D2}$

I_{D2} on for $v_{in} < -2.4$

for $v_{in} \geq -2.7$, D_2 off



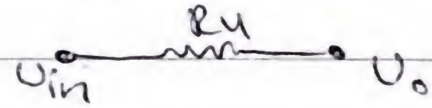
$v_2 = -2.7$

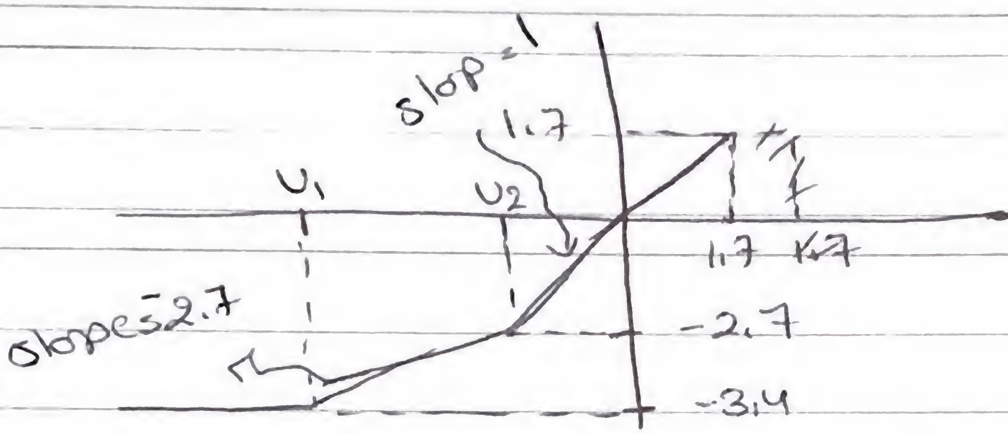
@ $v_{in} = v_2 \Rightarrow v_o = \dfrac{-2.7}{4} - \dfrac{3}{4}(2.7)$

for $v_2 < v_{in} \leq v_3$ $= -2.7$

D_1, D_2 & D_3 off

$v_o = v_{in}$





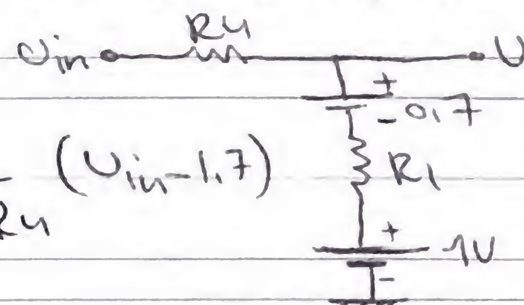
ⓐ $v_{in} = v_3$, D_3 Turns on

~~$V_o = 4.70\ 8\ v_3 = 1.7$~~

$V_o = 1 + 6V = 1.7\,V = V_{in}$

$\therefore v_3 = 1.7$

⊛ for $v_{in} > v_3$, D_1, D_2 off , D_3 on



$$v_o = 1.7 + \frac{R_1}{R_1 + R_4}(v_{in} - 1.7)$$

$$= 1.7 + \frac{1}{4}(v_{in} - 1.7)$$

$$= \frac{1}{4} v_{in} + \frac{3}{4}(1.7)$$

$$= \frac{1}{4} v_{in} + \frac{5.1}{4}$$

Subject: ______ / /

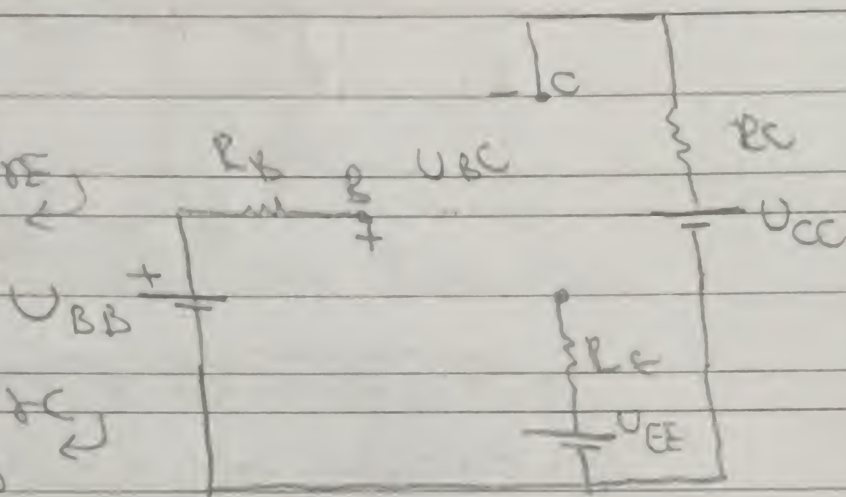
$$V_o = \begin{cases} -3.4 & V_{in} \leq -5.5 \\ \frac{1}{4}V_{in} - \frac{8.1}{4} & -5.5 \leq V_{in} \leq 1.7V \\ V_{in} & -2.7 \leq V_{in} \leq 1.7V \\ \frac{1}{4}V_{in} + \frac{5.1}{4} & V_{in} \geq 1.7 \end{cases}$$

Test Two :-

$$\cancel{\frac{dI_s}{dT} = 0.12 I_s} \;,\; \cancel{\frac{dI_D}{dT} = ?} \;\cancel{@ V_D = 0.7V}$$

Subject: ______ / /

c) if we assume (cut off)



$V_{BE} = -5.3 < V_{\gamma E}$
$\rightarrow$ JE is R.b

$V_{BC} = 3.7 > V_{\gamma C}$
$\Rightarrow$ J_C F.b

$\Rightarrow$ npn is in reverse Active Region

$$I_B = \frac{V_{BB} - V_B}{R_B} = \frac{\left[V_{BB} - (V_{\gamma C} - R_C I_C + V_{CC})\right]}{R_B}$$

$$= \left[(V_{BB} - V_{\gamma C} - V_{CC}) - R_C (1+\beta_R) R I_B \right] / R_B$$

$$I_B = \frac{V_{BB} - V_{\gamma C} - V_{CC}}{R_B + (1+\beta_R) R_C}$$

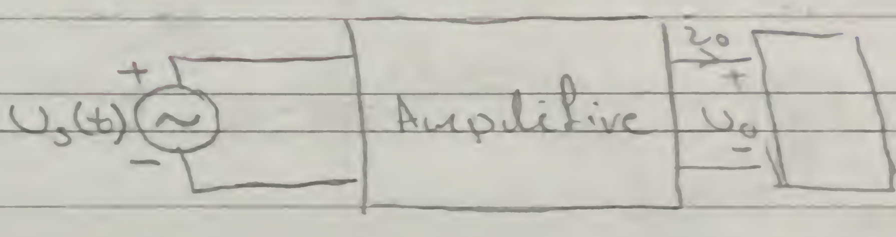
$= 2.87 \mu A$

$$\bar{I}_E = \beta_R \bar{I}_B = 28.7\,\mu A$$

$$\bar{I}_C = -(1+\beta_R)\bar{I}_B = -57.4\,\mu A$$

$$V_B = \text{--}, \; V_C = \text{--}, \; V_E =$$

Example :- Transistor as amplifire



يضخم الاشارة

The amplifire amplifies The signal $V_s(t)$

$$V_o = \underbrace{A_V}_{\text{Voltage gain}} V_s(t)$$

العلاقة خطية ويلزم تشتغل بحيث انه يكون

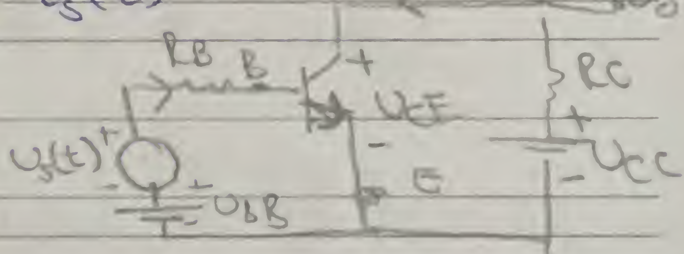
$\bar{I}_C = \beta_F \bar{I}_B$ (forward active) تقريبا

$V_s(t)$ = is a small (small amplitude) signal

Subject: ________ / /

The amplifire must perserve The shape of the input signal (shape of v_{out} is the same of the shap of $v_s(t)$) and this done by keeping A_v constant

current gain ← $-i_o = A_I \, i_s(t)$



$R_B = 100K$

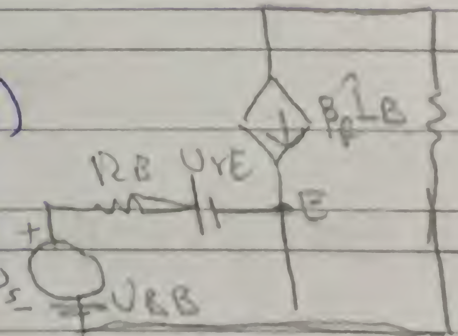
$R_C = 4K$

$V_{CC} = 12V$

$V_{BB} = 1.7V$

$\beta_F = 200$, $\beta_R = 1$, $V_{\gamma E} = 0.7V$

$V_{\gamma C} = 0.5V$, $V_A = \infty$



$I_B = I_{BQ} + i_B(t)$

$I_C = I_{CQ} + i_c(t)$

$V_{CE} = V_{CEQ} + v_{ce}(t)$

→ ac signal component

→ dc component

→ instantaneous signal

Subject: ______________ / /

* npn is forward active :-

$$v_S(t) = V_m \sin \omega t \quad mV$$

$$V_m = 100$$

$$i_B = \frac{[V_{BB} + v_S(t)] - V_{\gamma E}}{R_B}$$

$$= \frac{V_{BB} - V_{\gamma E}}{R_B} + \frac{v_S(t)}{R_B}$$

$$= I_{BQ} + i_B(t)$$

$$I_{BQ} = 10 \mu A$$

Subject: ________ / /

$$v_o = v_{CE} = V_{CC} - R_C \hat{I}_C$$

$$= V_{CC} - R_C [I_{CQ} + i_c(t)]$$

$$= (V_{CC} - R_C \hat{I}_{CQ}) - R_C \hat{I}_c(t)$$

$$= V_{CEQ} + v_{ce}(t)$$

$$V_{CEQ} = V_{CC} - R_C \hat{I}_{CQ}$$

$$= 12 - 4 \times 2 = 4V$$

$$v_{ce}(t) = -R_C \dot{i}_c(t) = -4 \times 0.2 \sin \omega t$$

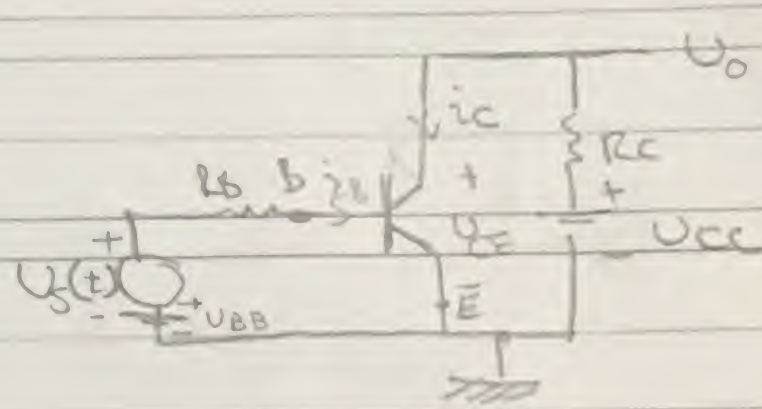
$$= 0.8 \sin \omega t$$

$$i_c(t) = \beta_F v_s(t) / R_B$$

$$v_{ce}(t) = -R_C I_c(t) = -\frac{\beta_F R_C v_s(t)}{R_B}$$

$$A_v = \frac{v_{ce}(t)}{v_s(t)} = -\beta_F R_C / R_B = -8$$

Subject: ______________ / /



$V_{CC} = 12V$, $V_{BB} = 1.7V$, $R_B = 100k$

$R_C = 4k$, $\beta_F = 200$, $\beta_R = 1$, $V_A = \infty$

$V_{\gamma E} = 0.7$, $V_{\gamma C} = 0.5$

$I_{BQ} = 10\mu A$, $I_{CQ} = 2mA$, $V_{CEQ} = 4V$

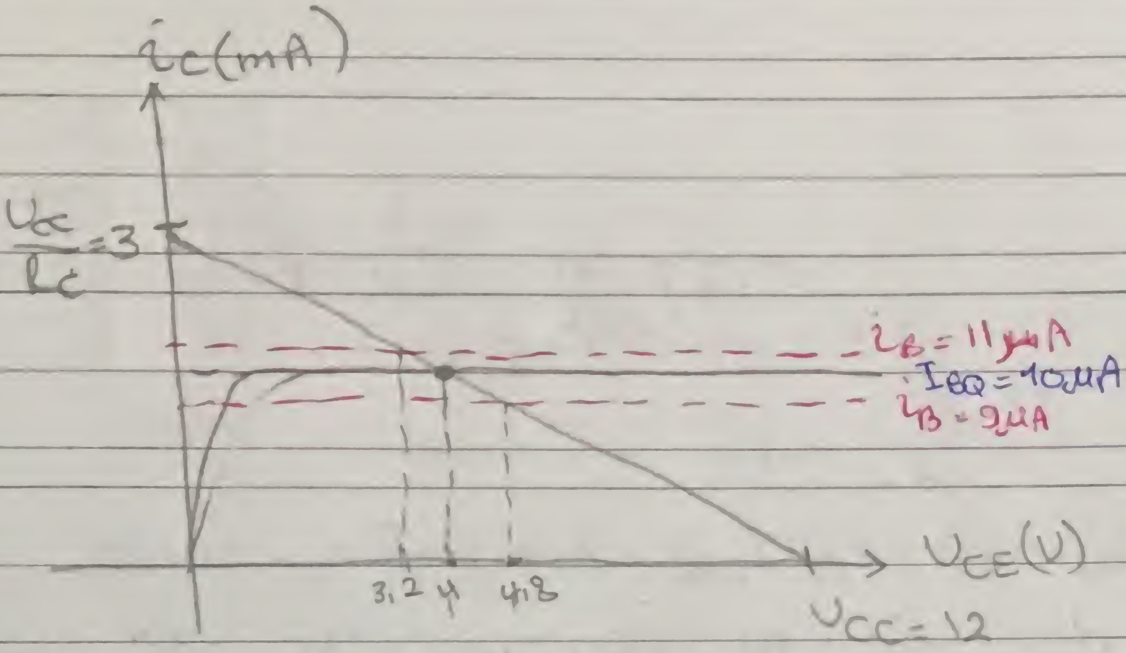
static load line

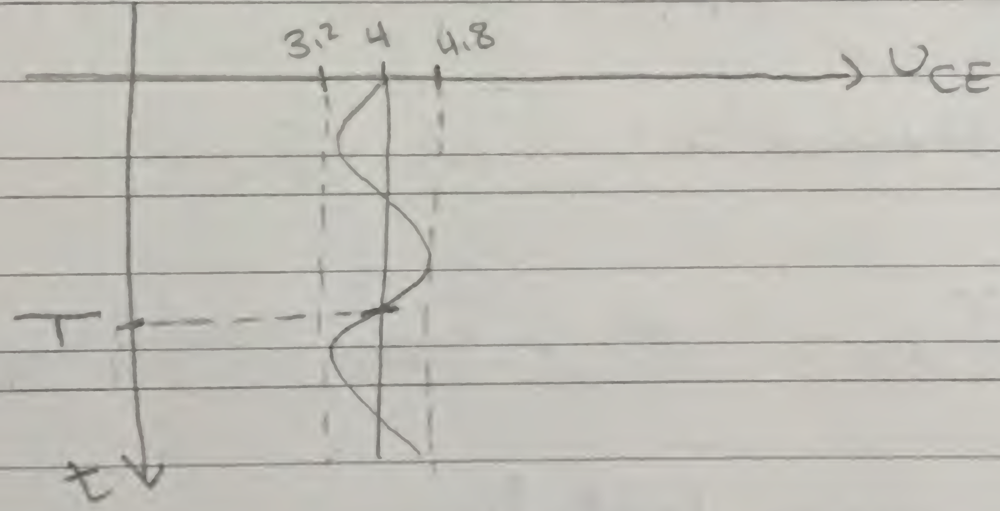
$$i_c = \frac{V_{CC} - V_{CE}}{R_C}$$

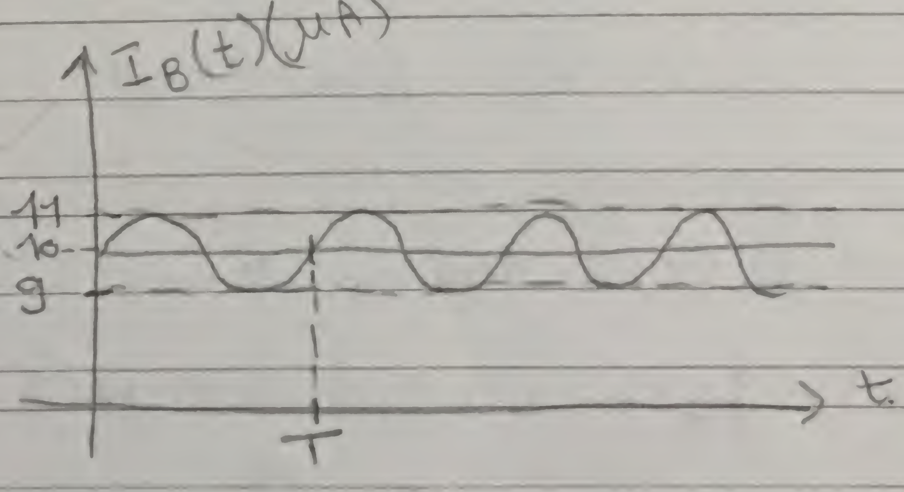
$V_s(t) = 100 \sin \omega t \ mV$

$i_B(t) = 1 \sin \omega t \ \mu A$

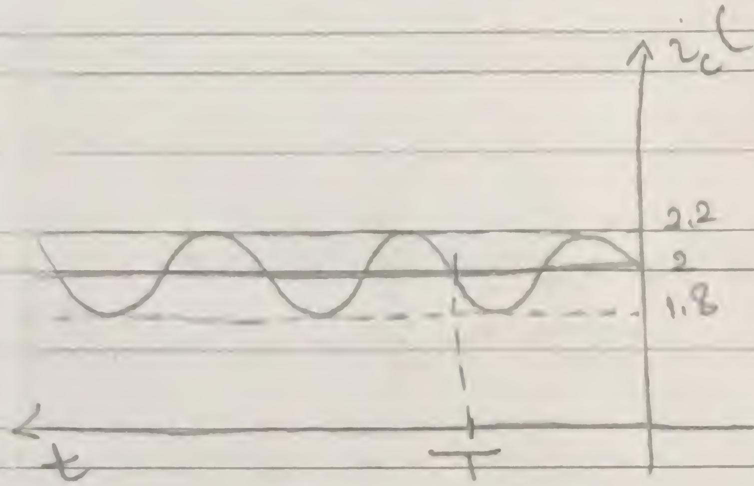
$i_c(t) = 200 \sin \omega t \ \mu A$


$i_C(mA)$
$\frac{U_{CC}}{R_C}=3$
$i_B = 11\mu A$
$I_{BQ} = 10\mu A$
$i_B = 9\mu A$
3,2
4
4,8
$U_{CE}(V)$
$U_{CC}=12$

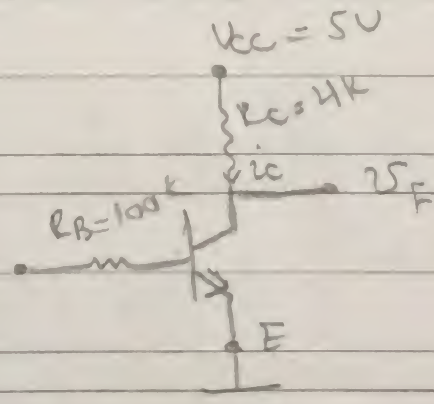

3,2
4
4,8
U_{CE}
T
t


$I_B(t)(\mu A)$
11
10
9
t
T

Subject: ______ / /



عند غالبا ما تكون نقطة التشغيل في المنتصف لتكون لها
نفس البعد في الزيادة والنقصان



$V_{\gamma E} = 0.7V$

$V_{\gamma C} = 0.5V$

$\beta_F = 100$

if $V_{BB} = 0 \Rightarrow$ npn is cut off

$\Rightarrow v_F = V_{CC} = 5V$

if $V_{BB} = V_{CC} = 5V$

Assume npn is forward Active

$I_B = \frac{V_{BB} - V_{\gamma E}}{R_B} = \frac{5 - 0.7}{100k} = 43\mu A$

Subject: ______________ / /

$I_C = \beta_F I_B = 4.3 \text{ mA}$

$V_F = V_{CE} = V_{CC} - R_C I_C$

$= 5 - 17.2 = -12.2 < V_{CEsat}$

assumption is wrong

npn is saturated

$\Rightarrow I_B = 43\,\mu A$

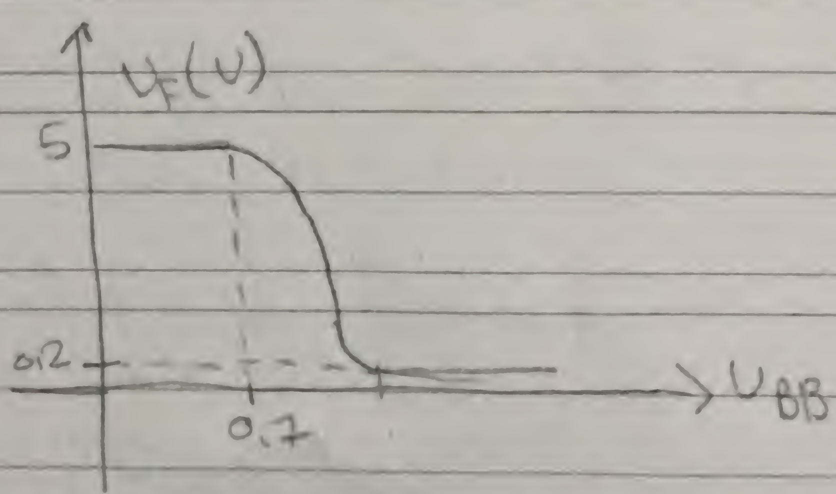
$v_F = V_{CE} = V_{CEsat} = 0.2V$

$i_C = \dfrac{V_{CC} - V_{CEsat}}{R_C} = \dfrac{4.8}{4} = 1.2mA$

inverter

V_{BB}	$V_{CE} = v_F$
0	5
5	0.2

v_{in}	V_o
L	H
H	L



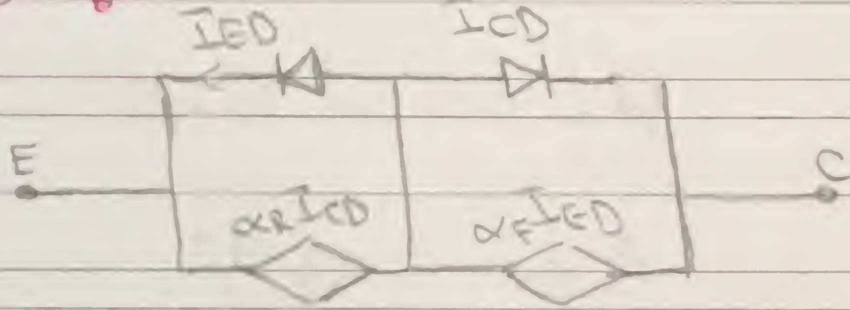
Subject: ch6 ⇒ 3 sections

10/6/2017 add 6.28, 6.29, 6.35
6.67

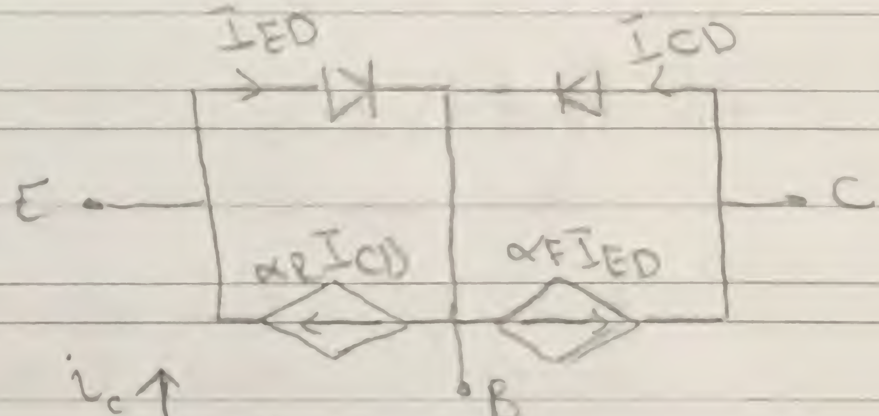
Tutorial

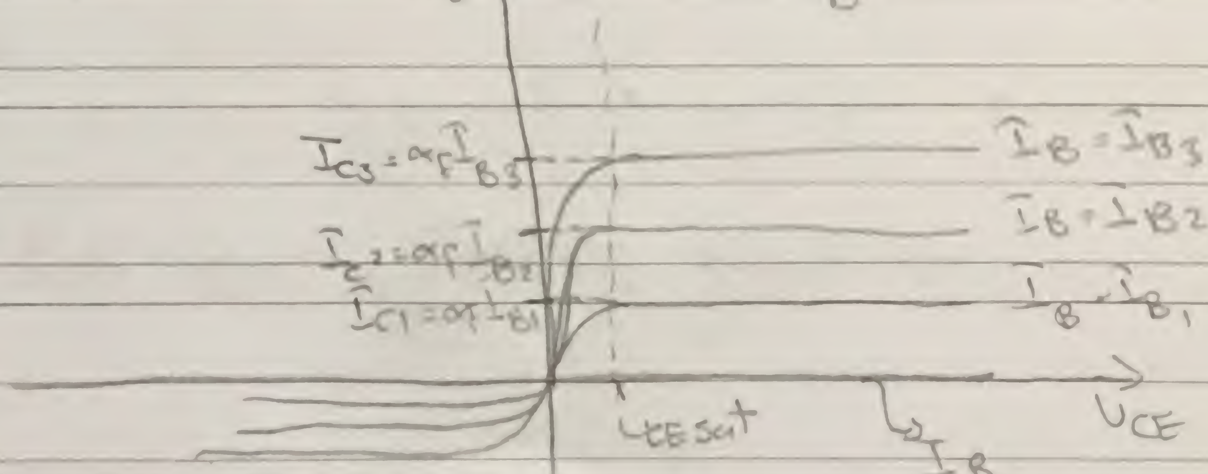
EM model :-

npn ⇒



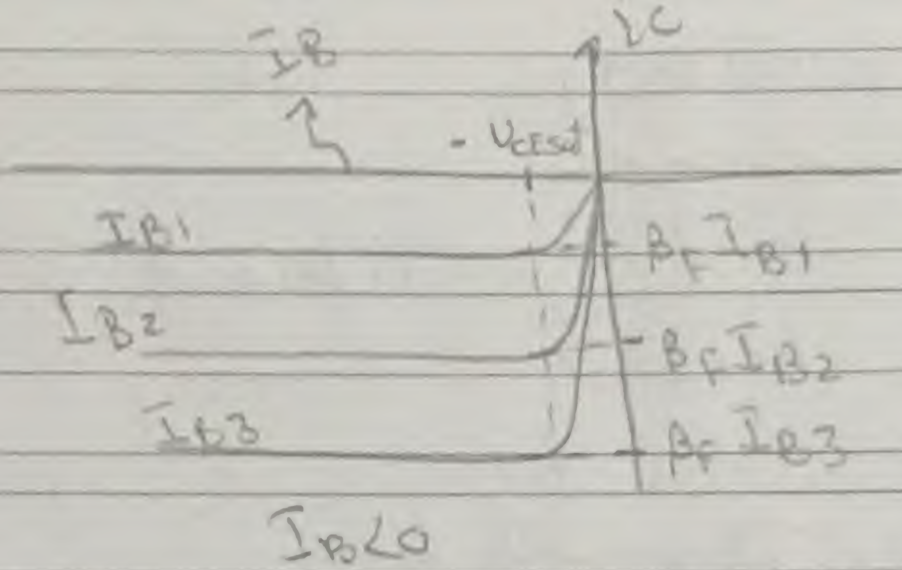
pnp ⇒





$I_B > 0$

Subject: ________ / /

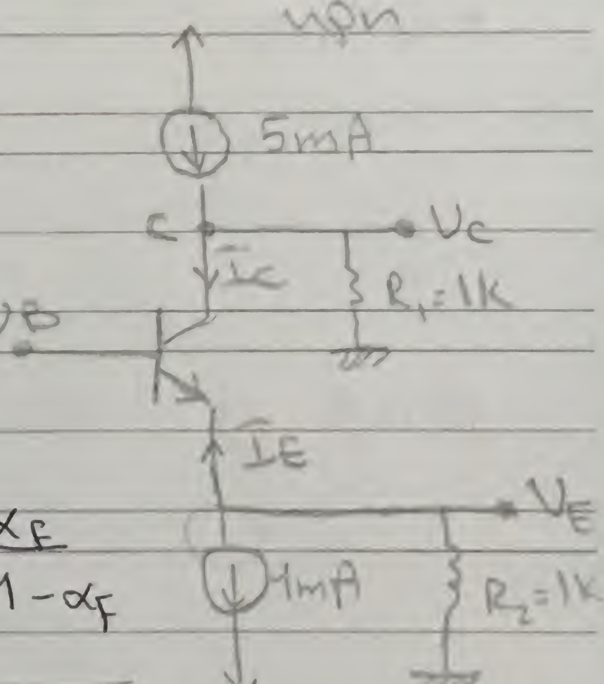


P6.55 in S&S :-

Assume $\alpha_F \cong 1$

$V_\gamma = 0.5V$

1) find V_C & V_E for $V_B = 0$



$$\lim_{\alpha_F \to 1} \beta_F = \lim_{\alpha_F \to 1} \frac{\alpha_F}{1-\alpha_F}$$

$\boxed{** \quad \alpha_F \to 1 \Rightarrow \beta_F \to \infty}$ always

$\Rightarrow$ Base current is neglected ($I_B = 0$)

$\Rightarrow I_E = -I_C$

Subject: ________ / /

Assume npn is cut of

$V_E = -1V \Rightarrow V_{BE} = V_B - V_E = 1V > V_{\gamma E}$

$\Rightarrow$ npn is either f.A or sat

Assume npn is f.A ($V_{BE} = V_{\gamma E} = 0.5V$)

$V_E = V_B + V_{EB} = V_B - V_{BE} = -0.5V$

$V_C = R_1 I_1 = R_1(5 - I_C) = R_1(5 + I_E)$

$I_E = -(1 + I_2)$, $I_2 = \frac{V_E}{R_2} = \frac{-0.5}{1k\Omega} = -0.5mA$

$I_E = -0.5mA$

assumption correct

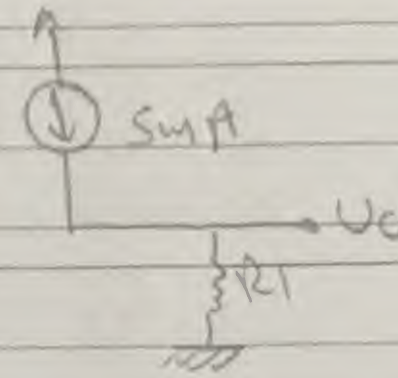
$V_C = R_1(5 - 0.5) = 4.5R_1 = 4.5V$

$V_{CE} = V_C - V_E = 5V > V_{CE\,sat}$

b// (4) Range of V_B for wich npn is cut off

npn is cut off $\Rightarrow V_{BE} < V_{\gamma E}$

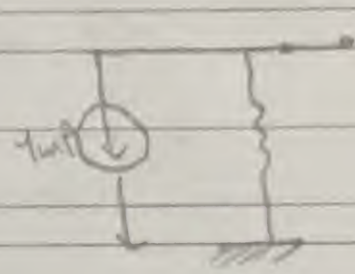
Subject: ______________ / /



$U_{BE} = U_B - U_E$

$U_E = -1V$

$U_{BE} = U_B + 1$



$U_{BE} < U_{\gamma E} \Rightarrow U_B + 1 < 0.5$

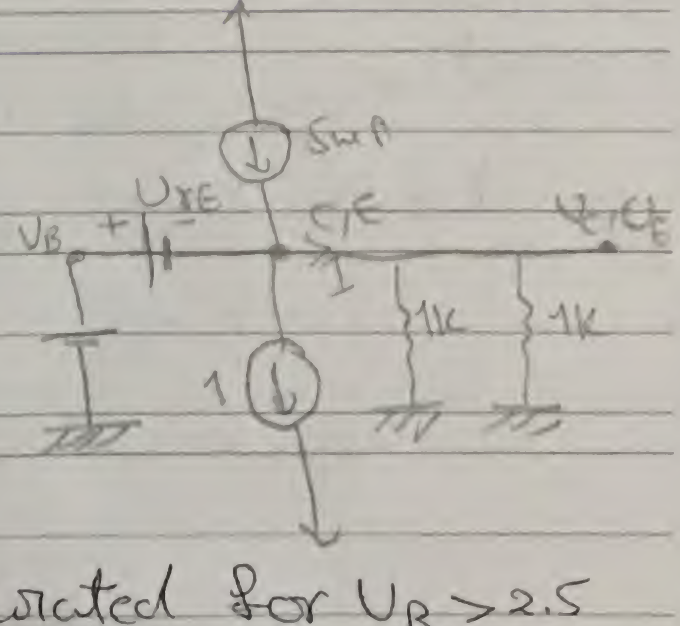
$\Rightarrow U_B < -0.5$

$U_C = 5R_1 = 5V$

(2) Range of U_B for wich npn is saturated Assume $U_{CEsat} = 0$

$I = 5 - 1 = 4mA$

$\Rightarrow U_C = U_E = 2V$



$U_B = U_{\gamma E} + U_E$

$= 2.5V$

npn is saturated for $U_B > 2.5$

Subject: ______________ / /

* معلومه واحده نطلع المطالب

P 6.57 :

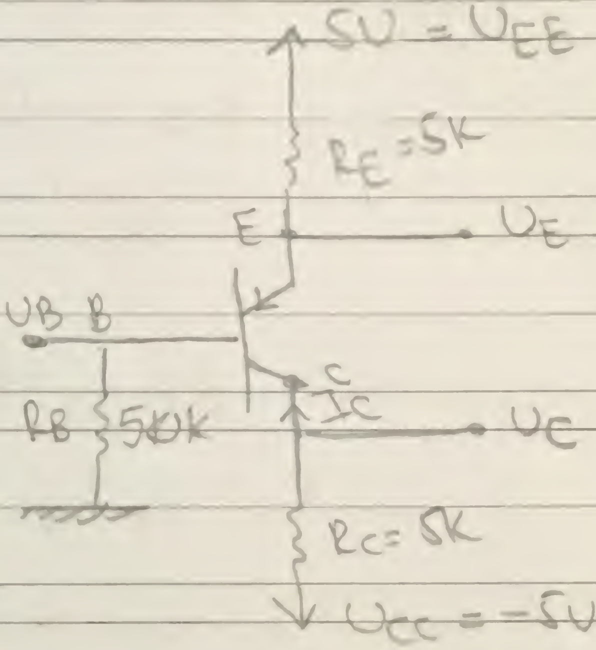
$|V_{BE}| = 0.7$

$V_{\gamma E} = 0.7$

Given : $V_E = 1.2V$

find I_B, I_C, V_E

β_F, α_F



$$I_E = \frac{V_{EE} - V_E}{R_E} = 0.76\,mA$$

BJT is npn & $I_E > 0$

$\Rightarrow$ pnp is f.A or sat

$V_{BE} = -V_{\gamma E} = -0.7V$

$V_B = V_{BE} + V_E = 0.5V$

$$I_B = \frac{0 - V_B}{R_B} = \frac{-0.5}{50\,k\Omega} = -1\,\mu A$$

Subject: ________ / /

Assume pnp is f.A

$$I_E = -(1+\beta_f) I_B$$

$$\beta_f = -\left(\frac{I_E}{I_B} + 1\right) = -\left(\frac{\cancel{0,}760}{-10} + 1\right)$$

$$\beta_f = 75 \Rightarrow \alpha_f = \frac{75}{76} = 0,987$$

$$I_C = \beta_f I_B = -0,75 \text{ mA}$$

$$V_C = V_{CC} - R_C I_C$$
$$= -5 - 5(-0,75)$$
$$= -5 + 3,75 = -1,25 \text{ V}$$

$$V_{CE} = V_C - V_E = -1.25 - 1.2$$
$$= -2.45 \text{ V}$$

$$V_{CE} < -V_{CE\,sat}$$

$\Rightarrow$ pnp is f.A as assumed